

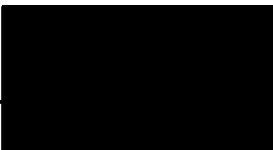
Gender Differences In Spatial Ability Within Virtual Reality.

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A thesis submitted in fulfilment of the requirements of the University of Abertay
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I certify that this thesis is the true and accurate version of the thesis approved by the examiners.

Signed ...  Date...27/oct/2004
(Director of Studies)

INDEX

Table of contents.....	II
List of tables.....	XII
List of figures.....	XIV
List of ANOVAS.....	XVII
Acknowledgements.....	XIX
Abstract.....	XX

Table of Contents

1. Ch 1 Gender Differences in Spatial Ability Within Virtual Reality	1
1.1 Gender Differences in Virtual Reality	3
1.1.1 Presence	4
1.1.2 Comprehension of Science	9
1.1.3 Learning Styles	9
1.1.4 Mental Rotation	12
1.1.5 Transfer of Knowledge	13
1.1.6 Simulator/Cyber Sickness	14
1.1.7 Navigating Strategies	16
1.1.8 Place Learning Ability	17
1.1.9 Transference of Spatial Knowledge	17
1.2 What has been done about Gender/Sex Differences?	18
1.2.1 Spatial Ability	20

1.2.2	Navigating Skills	20
1.2.3	Gender/Sex Differences	21
1.2.4	The Relevance of this present Research	22
1.2.5	The Importance of this Research	23
1.3	How the study will be carried out	24
1.3.1	Mental Rotation Tests	25
1.3.2	Virtual Reality Phase of Testing	27
1.3.3	General Layout	30
1.4	Summary	31
2. Ch 2	Mental Rotation.....	32
2.1	Brief History of Spatial Testing	33
2.2	Spatial Ability	36
2.2.1	Spatial Cognition	37
2.3	The Importance of Mental Rotation	39
2.3.1	Shepard and Metzler's Study of Mental Rotation	40
2.3.2	The Imagery Debate	44
2.3.3	Pavio's Dual Coding Model	46
2.3.4	Kosslyn's Computational Model	49
2.3.5	Kosslyn's Theory Mentions Four Properties of the Medium	51
2.3.6	Evidence in Favour of Analogue Coding	54
2.3.7	Scanning and Mental Rotation	55
2.3.8	Pylyshyn's Propositional Theory	58
2.3.9	Predicate Calculus	61
2.3.10	Pylyshyn on Mental Rotation	63
2.3.11	The Hybrid Theory	64

2.4	The Advantages of Imagery and Mental Rotation	67
2.5	Sex/Gender	69
2.6	Mental Rotation Studied by fMRI.....	72
2.6.1	Problems with Laterisation Tests	73
2.6.2	Eliminating Gender Differences: Practice	77
2.6.3	Stereotyping/Self-Perception:	81
2.7	Summary	82

3. Ch 3 Encoding and Navigating the

Environment..... 84

3.1	Perceiving Space in Natural Environments	85
3.2	Monocular Cues	87
3.3	Space around a moving observer	88
3.4	Linear Perspective	89
3.4.1	How we perceive perspective	90
3.4.2	Interpretation of perspective: Nature or Nurture?	91
3.4.3	The Necker Cube	94
3.4.4	A Computational Model of the Mind	96
3.5	Familiarity and Shadows	97
3.5.1	Countershading	100
3.5.2	Shading and Motion Perception	101
3.5.3	Can shape from shading prevent us from falling over?	102
3.5.4	Perception of depth is a hard-wired function	103
3.5.5	Underlying Neural Mechanisms	104
3.6	Motion Parallax	105

3.7	Stereopsis	106
3.8	Navigation within a Three-Dimensional Environment	107
3.8.1	Sensory Conflict	108
3.9	Navigational Awareness	110
3.9.1	Models of Spatial Awareness and Navigation	115
3.10	Cognitive Maps	117
3.11	Siegal and White Model	118
3.12	The Information Processing Account	122
3.13	Virtual Reality and Navigation	124
3.13.1	Neuroscience, Virtual Reality and Human Spatial Navigation	126
3.13.2	Neuroscience, Navigation and Gender Differences	128
3.13.3	Gender Differences in Navigating	131
3.14	Evolution Explanation of Sex Differences in Navigation	133
3.14.1	Evolutionary Theory and Navigation	134
3.15	Summary	138

4. Ch 4 Nature or Nurture

.....	141
4.1 Nature – Sex Differences	143
4.2 Evolutionary Theory and Spatial Dimorphism	144
4.3 Sex Differences	146
4.4 The Biological Approach	151
4.5 The Hormonal Approach	153
4.5.1 Hormonal Influence on Behaviour	154
4.6 Congenital Adrenal Hyperplasia (CAH)	158

4.7	Brain Laterisation	160
4.8	Hormonal Fluctuations	164
4.9	Conclusion to Sex Differences	164
4.10	Nurture – The Environmental Approach to Gender Differences	165
4.11	Nature and Nurture	166
4.12	The Feminist Approach	168
4.13	Socialisation and Education	169
4.14	In the Home	174
4.15	Environmental Influences that may affect Performance	176
4.15.1	Motivation	176
4.15.2	The Self-Efficacy Theory	177
4.15.3	The Behavioural Theory	178
4.15.4	The Cognitive Theory	178
4.15.5	The Humanistic Theory	179
4.15.6	Development of Student Motivation	180
4.15.7	Extrinsic or Intrinsic Motivation	181
4.16	Practice and Training	182
4.16.1	The Effect of Training	183
4.16.2	Computer Experience	185
4.16.3	Motivation, Computer Games and V.R	187
4.16.4	Gender Differences in Computer Game Play	188
4.17	Stereotyping and Self-Perception	189
4.17.1	Gender Differences in Self-Evaluation	190
4.17.2	Self-Perception and Academic Performance	191
4.17.3	Stereotyping in Academia:	192

4.17.4 Parental Expectations	193
4.17.5 The Perpetuation of Stereotypical Gender Roles through Computer Games	194
4.18 Summary	195

5. Ch 5 Phase One Experiments

.....	198
5.1 Purdue Visualisation of Rotations (ROT)	198
5.2 Shepard and Metzler Mental Rotation Test:	200
5.3 Experiment 1 – Purdue Visualisation of Rotation	204
5.4 The Design:	206
5.4.1 Results of the ROT	208
5.4.2 Discussion	209
5.5 Experiment Two – 3D “Wire-frame” Test	210
5.5.1 Present Experiment	214
5.5.2 The Design	216
5.5.3 Results for the Wire-frame Test	221
5.5.4 Time taken to complete the 3D “Wire-frame” Test	221
5.5.5 Discussion	223
5.6 Experiment Three – Solid or Shaded 3D Shapes	224
5.6.1 Shape from Shading	225
5.6.2 Experiment Three – “Solid” Shape Test	227
5.6.3 The Design	228
5.6.4 Results Section – Time taken to complete the Solid Shapes 3D Test...	229
5.6.5 The number of correct answers in the Solid 3D Test	231

5.6.6	Discussion	231
5.7	Chapter Summary	234
5.7.1	Response Rates	238
5.7.2	Faculty	239
5.8	To Conclude	241

6. Ch 6 Phase Two Experiments

.....	243
6.1	The Bent Twig 244
6.2	Testing Phases 244
6.3	First Test Motivation 245
6.3.1	Method 246
6.3.2	Results: Motivation Test 247
6.3.3	Time taken to complete the Motivation Test 249
6.3.4	Discussion 250
6.4	Experiment Two – Practice Experiment 253
6.4.1	Method255
6.4.2	Results for Accuracy 256
6.4.3	Discussion 258
6.5	Experiment Three – Self Perception and the Mental Rotation Test 260
6.5.1	Self Perception Test 262
6.5.2	Results for the Self-Perception ROT 264
6.5.3	Discussion 267
6.6	Chapter Summary 269

7. Ch 7 Phase Three Experiments

.....	272
7.1 Previous Phases of Testing	272
7.2 Phase Three	274
7.3 Mental Rotation Tests	277
7.3.1 Results for the Mental Rotation Tests:	279
7.3.2 Results for the Wire-frame and Solid Tests:	280
7.3.3 Time taken to complete the 3D Mental Rotation Tasks	283
7.4 Correlations	285
7.4.1 Maths Ability and Accuracy on the MRTs	286
7.5 Discussion	289
7.6 The Virtual Environment	292
7.6.1 Design	296
7.6.2 Test 1 – Way Finding	303
7.7 Correlations in Mental Rotation and Navigation Tests	309
7.7.1 Time taken to complete the Solid and Wire-frame MRTs and the number of hours spent playing computer games per week	310
7.7.2 The percentage of correct answers in 2D ROT, 3D Wire-frame and 3D Solid Test and the number of hours spent playing computer games per week	312
7.7.3 Number of years computer experience and accuracy on the three MRTs	313
7.7.4 Performance on the MRTs and VE Tests:	314
7.7.5 VE Tests, maths grade, computer experience and hours spent Playing computer games per week	315

7.7.6	Correlation between the three MRTs and the layout, route and Orientation tests for Males and Females separately	317
7.8	Discussion	319
7.8.1	Correlations	321
7.8.2	General Discussion	332
Ch 8 Chapter One Revisited		
.....		340
8.1	Study one: Presence.....	341
8.1.1	Further explanations obtained from this present research.....	345
8.2	Study two: Learning impaired students.....	348
8.2.1	Further explanations obtained from this present research.....	349
8.3	Study Three: Mental rotation.....	350
8.3.1	Further explanations obtained from this present research.....	351
8.4.	Study Four: Simulator/cyber sickness:.....	354
8.4.1	Further explanations obtained from this present research.	357
8.5	Study Five: Transfer of Spatial Knowledge	358
8.5.1	Further explanations obtained from this present research.....	358
8.6	Study Six: Navigation strategies.....	363
8.7	Study Seven: Place learning ability.....	368
8.8	Study Eight: Transference of spatial knowledge.....	371
8.8.1	Further explanations obtained from this present research.....	372
8.9	Project achievements, contribution to knowledge and future research....	373
8.9.1	Summary of main findings.....	374
8.9.2.	Encouraging Females to be part of the Computer Revolution.....	382
8.10.	Conclusion.....	390

Appendices

Appendix 1	Copy of ROT test paper instructions.....	393
Appendix 2	Two examples from the ROT.....	395
Appendix 3	Questionnaire.....	396
Appendix 4	Subject information sheet.....	397
Appendix 5	Consent form.....	398
Appendix 6	Way-finding test.....	399
Appendix 7	House Layout.....	400
Appendix 8	Visualisation/Alternative routes test.....	401
Appendix 9	Visualisation/orientation test.....	402
Appendix 10	Landmark test.....	403

References

.....	404
-------	-----

Anovas	424
--------------	-----

List of Tables

Table 6.1	Mean percentage of correct answers in the 3D Solid MRT... ..	248
Table 6.2	Mean (in seconds) and standard deviations to complete the 3D MRT.....	250
Table 6.3	Means and standard deviation for the number of correct answers given in the paper and pencil “Solid” MRT	257
Table 6.4	Means and standard deviation for the number of correct answers Given in the ROT for gender by self-perception group	265
Table 6.5	Means and standard deviation for the two main effects, self perception group and gender	265
Table 7.1	Mean percentage of correct answers in the ROT in the three Conditions gender, faculty and age	279
Table 7.2	Mean percentage of correct answers and standard deviation for the Wire frame and Solid tests – gender, faculty and age	281
Table 7.3	Means and standard deviations for the time taken to complete the Wire frame and Solid MRTs – gender, faculty and age	284
Table 7.4	Correlation table for percentage of correct answers on the three MRTs and the maths grade of the participants	286
Table 7.5	Correlation between maths ability and the percentage of correct answers in the three MRTs for female participants	287
Table 7.6	Correlation between maths ability and the percentage of correct answers in the three MRTs for male participants	288
Table 7.7	Means and standard deviations for the time taken to complete the way-finding instructions – gender, faculty and age	304
Table 7.8	Mean number of correctly placed rooms etc in the Layout Test	

	with the three factors – gender, faculty and age	305
Table 7.9	Means and standard deviations for the Route test with three factors – gender, faculty and age	306
Table 7.10	Means and standard deviations for the Orientation test with three Factors – gender, faculty and age	306
Table 7.11	Means and standard deviations for the number of Landmarks for the three factors – gender, faculty and age	308
Table 7.12	Full correlation matrix	310
Table 7.13	Correlation between time taken to complete the Solid 3D MRT	311
Table 7.14	Correlation between the percentage of correct answers in the three MRTs	312
Table 7.15	Correlation between percentage of correct answers in the three MRTs and the number of years computer experience	313
Table 7.16	Correlation between percentage of correct answers in the three MRTs and performance in the VE Test	314
Table 7.17	Correlations between performance on the VE Tests with maths ability, computer experience and number of hours playing computer games	315
Table 7.18	Correlation between MALE performances on the MRTs and the Layout, Route and Orientation Tests	317
Table 7.20	Correlation between FEMALE performances on the MRTs and the Layout, Route and Orientation Tests	318

List of Figures

Fig 1.1	A view of the Virtual Marshland	5
Fig 1.2	Shows one example from the “Wire-frame” Mental Rotation Test ...	27
Fig 1.3	Example from the Purdue Visualisation of Rotation Test.....	27
Fig 1.4	Part of the interior of the Virtual House – view from sitting room onto The swimming pool	29
Fig 1.5	Interior of the Virtual House – looking from front door, through lounge to kitchen at rear	30
Fig 2.1	Example of paper folding test	35
Fig 2.2	A pair of stimuli from a Shepard and Metzler style MRT	41
Fig 2.3	Dual coding model for memory and cognition	48
Fig 3.1	Convergence – two viewing axes of a pair of eyes	86
Fig 3.2	Paris Street: Rainy day by Gustave Caillebote	90
Fig 3.3	Converging lines as indicating linear perspective	91
Fig 3.4	The Muller-Lyer illusion	93
Fig 3.5	Two representations of the Necker Cube	95
Fig 3.6	Shaded circles	98
Fig 3.7	The brain assumes light comes from above	99
Fig 3.8	Counter shading on a shark	101
Fig 3.9	Gibson and Walk’s (1960) visual cliff experiment	104
Fig 3.10	Eye changing position and cues to depth	105
Fig 3.11	Example of Motion Parallax	106
Fig 3.12	A model of Navigation, after Darken and Peterson (2002)	117
Fig 3.13	Gron et al (2000) and the Maze Navigation Test	128

Fig 3.14	Performances of control in the Morris Water Tank	130
Fig 4.1	A cross section of the human brain	151
Fig 5.1	Item 7 from the 20 item version – Purdue Visualisation (ROT) Test	207
Fig 5.2	Shepard and Metzler (1971) Style Stimuli	210
Fig 5.3	Old style stereoscopic viewer	212
Fig 5.4	Old style stereo card	213
Fig 5.5	3D Elsa shutter glasses	213
Fig 5.6	3D Wire frame Test	217
Fig 5.7	Graph showing the interaction between gender and faculty in the time (in seconds) taken to complete Wire frame 3D MRT	223
Fig 5.8	Pair of mirror image “Solid” shapes in 3D “Solid” MRT	226
Fig 5.9	Interaction between gender and faculty in Solid 3D Test	230
Fig 6.1	Mean percentage of correct answers in Solid 3D MRT	248
Fig 6.2	Mean time (in seconds) to complete the 3D Solid MRT	249
Fig 6.3	Mean number of correct answers in 2D “Solid” MRT	256
Fig 6.4	Practice over time had a greater effect on males than females	257
Fig 6.5	Mean percentage of correct answers in the ROT Test	264
Fig 7.1	Percentage of correct answers according to gender in the Wire frame and Solid 3D MRTs	280
Fig 7.2	Percentage of correct answers according to faculty in the Wire frame and Solid 3D MRTs	283
Fig 7.3	Mean time in seconds to complete Wire frame and Solid MRTs for Gender male and females	283
Fig 7.4	Mean time in seconds to complete Wire frame and Solid MRTs for Faculty, science and arts	283

Fig 7.5	Entrance hall and living room in the Virtual House	300
Fig 7.6	Interaction between gender and faculty in the orientation test.....	307
Fig 7.7	Possible influences of Spatial Visualisation on maths ability, mental rotation ability and performance on the VE Tests	325

List of ANOVAs

1. Results of the ROT(accuracy) ANOVA in phase one experiments.....	424
2. Results of the Wire-frame(time)ANOVA in phase one experiments.....	424
3. Results of the Wire-frame(accuracy)ANOVA in phase one experiments.....	425
4. Results of the Solid (accuracy)ANOVA in phase one experiments.....	426
5. Results of the Solid (time)ANOVA in phase one experiments.....	426
6. Results of the Motivation test (accuracy) ANOVA in phase two experiments.....	426
7. Results of the self-perception test (accuracy) ANOVA in phase two experiments.....	427
8. Results of the ROT test (accuracy) ANOVA in phase three experiments.....	427
9. Results of the Layout test (accuracy) ANOVA in phase three experiments.....	428
10. Results of the Landmark test (accuracy) ANOVA in phase three experiments.....	428

11. Results of the Visualisation test (accuracy) ANOVA in phase three experiments.....	429
12. Results of the Orientation test (accuracy) ANOVA in phase three experiments.....	429
13. Results of the timed Navigation test ANOVA in phase three experiments.....	430
14. Results of the Wire-frame and Solid test (accuracy) ANOVA in phase three experiments.....	431
15. Results of the Wire-frame and Solid test (timed) ANOVA in phase three experiments.....	432

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To God, for getting me through the strangest years of my life!

Abstract

The main question that this study addressed was whether the gender differences found in performance within Virtual Reality (VR) are due purely to innate spatial ability differences or due to, at least in part, environmental factors. Examination of the differences, as a function of virtual or real training environments, is important to understanding what can be accomplished with virtual environments and what aspects of VR needs to be studied further in order to maximise their effectiveness.

Contemporary research into VR has suggested sex differences in performance are due to females having a poorer innate ability to mentally rotate objects and that this ability underpins the ability to navigate successfully both real and a three-dimensional computer generated world. Mental rotation tests (MRT) were used to measure spatial ability as these have been shown to produce consistent and robust sex difference. Environmental factors such as motivation, self-perception and practice were used to manipulate performance on the MRTs to ascertain whether such factors were as important as biological differences. A virtual environment (VE) was also used to test participants on their visualisation, orientation and way-finding skills along with their ability to recall information from the VE

The main results showed that in seven of the nine MRTs and also in the VE tests, no significant sex differences were found. The conclusion was that although there are biological differences that have evolved a male advantage with regards to spatial ability, changes in society and the perception of gender roles has to some

degree offered females experience with spatial tasks. Environmental factors have to be considered as the tests showed that practice can reduce and perhaps even eliminate differences in spatial performance although not necessarily at the higher end of problem solving. The Motivation and Self-perception tests clearly showed how such environmental factors either increase or indeed decrease performance depending on how they are manipulated.

With regards to VR and spatial ability, special attention has been given to the role of computer games companies. It has been recognised that games are an introduction to computer literacy and that games can improve spatial skills and interface proficiency. Girls are being discouraged from taking an active involvement in gaming because of the male orientated content of most games. Females are under-performing within VR and sex differences are one form of explanation however it is possible that lack of experience and lack of motivation to interact with computer technology are also important issues to be addressed.

Chapter One

Gender Differences In Spatial Ability Within Virtual Reality.

The main question that this study will address is whether the gender differences found in performance within Virtual Reality (VR) are due purely to innate spatial ability differences or due to, at least in part, environmental factors. However, the use of the term “gender” runs into problems of its own right from the outset. Throughout the literature gender and sex are used interchangeably although they have very different and very important definitions. There are in fact papers that refer to both terms but for no systematic reason. A further complication is that there are times when it is not known which term should be used i.e. a behavioural difference cannot be pinpointed to being a gender or sex difference. “Sex” is the biological term that refers to the functional difference between males and females and their reproductive potential and is determined by genes in chromosomes. “Gender” can be divided into gender role and gender identity, the former being the adoption of masculine or feminine behavioural traits that are deemed appropriate or characteristic of a particular gender, the latter being a persons private, subjective sense of maleness or femaleness. In this study the terms will be used according to their true definition except when referring directly to referenced research whereby the terms used by the authors will be used.

Another term that needs defining from the outset is that of “VR” which is “ a way for humans to visualise, manipulate and interact with computers and extremely complex data.” (Aukstakalnis and Blatner, 1992). VR has however become a universal term for the area of computing that takes the user into a synthetic environment. Many researchers prefer to use the term Virtual

Environment (VE) as it gives a more accurate and less contradictory description of the situation. Others argue that VE should only be used where a person perceives that they are either in or interacting with a virtual environment. Today however, the terms have become interchangeable and both VE and VR can be defined as being computer generated, simulated, three-dimensional environments that alter in real-time as manipulated by the user, therefore the technology is primarily concerned with allowing individuals to experience a synthetic form of reality (Mills and Noyes, 1999).

A major incentive for understanding why there are differences in human interaction, such as task performance, is because VR is being used more and more as an entertainment, educational and training medium as well as for medical purposes. Examination of the differences, as a function of virtual or real training environments, is important in order to understand what can be accomplished with virtual environments and what aspects of VR needs to be studied further in order to maximise their effectiveness. Little research has examined the role of gender or sex characteristics and abilities in determining just how effective VR can be with regard to training etc.

VR makes it possible for people to obtain spatial knowledge for an environment other than the one in which they are physically located. It therefore has the potential to be an invaluable tool with regards to education and training (Patrick et al 2000). When using VEs the participants have to learn and mentally represent the spatial characteristics of the computer-generated environment. VEs are being used, among many other things, in safety critical situations where there would

otherwise be risks involved if novice trainees were in contact with the actual environment such as training firefighters (Bliss, Tidwell and Guest, 1997) or teaching ground navigation to soldiers (Darken and Banker, 1998). Other areas where VR is being used is in helping neurologically impaired children to develop spatial concepts and relationships (Osberg, 1997) and diagnosing specific pathological conditions common in aging such as Alzheimer disease (Buckwalter *et al*, 1999). VR is also being used for system modeling particularly in engineering applications such as car design. It is also used for practicing surgery where students can use a scalpel and due to the force-feedback that VR can offer, can learn the right amount of pressure needed for invasive surgery (Krapichler, (1999)

The individual characteristics and prior abilities of trainees have been given consideration (Waller, 1999) since individual differences are already known to be a major source of variation in performance in real world spatial tasks (Bryant, 1982, Voyer, Voyer and Bryden, 1995). In studies of human-computer interaction, Egan (1988) and Vincente, Hayes and Williges (1987) have also found such individual differences. Gender or sex differences however, have had little attention.

1.1 Gender Differences In Virtual Reality

At this point it would be prudent to review the literature that shows gender or sex differences in performance within VR and to clarify the meaning of performance. Each study will be looked at in some detail and it will become clear that there is not any one definition of performance and that although the gender or sex

differences are varied, all appear to have their roots in an important cognitive function that comes under the rubric of spatial ability.

1.1.1. Presence.

Winn, Hoffman, Hollander, Osberg and Rose (1997) carried out research into the effect of student construction of VEs on the performance of high and low general ability students. (See Fig 1 for a view of the virtual environment) The students were children from grades 4 to 12 years. Students took teacher-constructed post-tests over the content they had been studying, they also took a test of general ability, Raven's "Progressive Matrices" (Raven, 1958) which is a test that is not affected by students' mastery of language.)

The main purpose of this study was to test the hypothesis that the unique experiences of building and visiting VEs would be more useful to some students than others. Learning in "traditional" classrooms often requires students to master abstract and esoteric symbol systems before they can understand content. Winn *et al* allowed the students to make decisions about how their "world" was to appear and behave. The students were then given the tools to actually build their world and afterwards to visit their VE and perform tasks in it. Winn *et al* believed that such an experience would be particularly helpful for students who do not do well with a more traditional, symbol-oriented pedagogy. Their finding was that children who had a low general ability, as measured on the Ravens test and who took part in the world building project, significantly outperformed those studying in the traditional classroom manner, as measured on post-test knowledge of the environment.

Spatial reasoning was also an important factor considered. Those students attending Middle and High School took spatial ability tests including card rotations, cube comparisons and paper folding. The results gave a measure of spatial reasoning and visualization ability. Students also completed a questionnaire and it was found that high spatial reasoning students reported that they experienced more enjoyment and presence than low spatial students did.

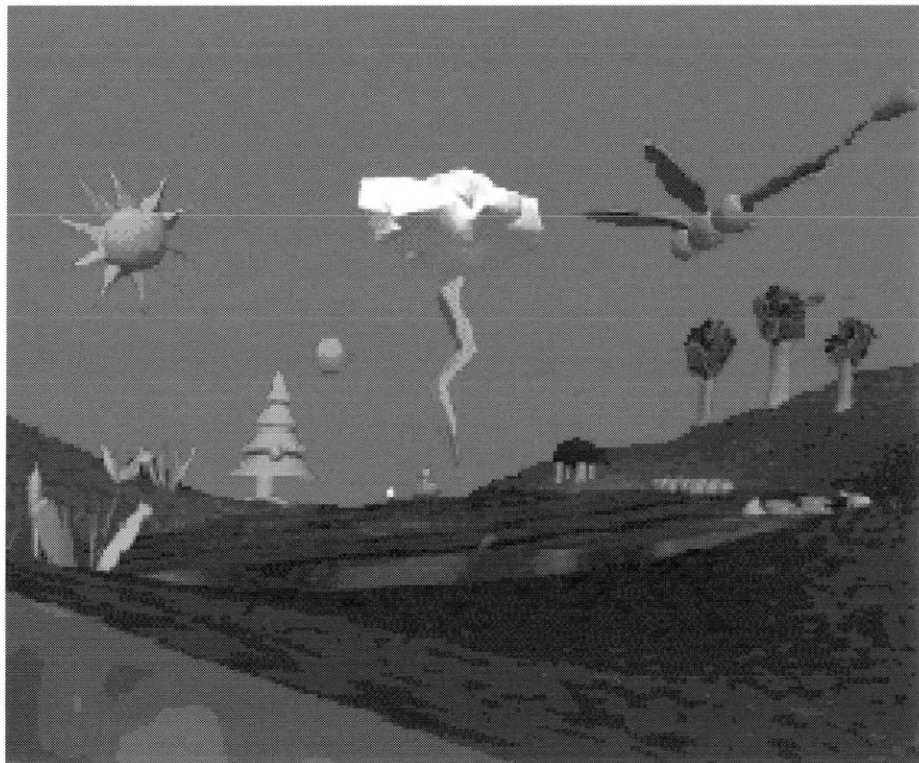


Figure 1.1. A view of the virtual marshland created by the children in tests conducted by Winn, Hoffman, Hollander, Osberg and Rose (1977).

Presence is fundamental to enjoyment and to performance in a virtual world and the role spatial reasoning plays in presence ratings is extremely important and gender was a factor that effected presence ratings. Important for this present

research was the fact that, in Winn's study, spatial reasoning ability did not affect presence ratings for boys but low spatial ability girls reported lower presence than high spatial girls did. In fact, boys reported higher levels of presence than girls did. Winn suggests that an explanation for this might be that the male advantage is perhaps due to boys having more exposure to computer games and having learned skills for manipulating the interface. He also suggested that boys "may be more easily fooled into believing a Virtual Environment is real whereas girls do not tend to be taken in so easily." Slater and Usoh (1993) suggested that VR has the ability to take the user to a virtual environment, leading to the "suspension of disbeliefs that they are in a world other than where their real bodies are located." If the suspension of disbelief is important to the feeling of "presence" and boys are more easily persuaded, then it is important to ascertain why that should be. Presence, Winn states, is a key to learning within VEs and is related to spatial reasoning ability and that gender is a factor that should not be ignored.

The nature and measurement of "presence" is problematic to say the least, as there is little agreement amongst those working in the areas of psychology, cognitive science, computer science and communications as to what it is. The term "telepresence" was first used by Minsky (1980) when referring to tele-operation technology. Such technology, he believed, gave the user the feeling of a remote presence whilst being in a different location by allowing them to see and feel what was happening. By 1991 this term was shortened to "presence" at the conception of the journal Presence, published by MIT press. Despite the controversy over definitions, the goal of the V.E. designer is to create an environment that is so

convincing that the participant suspends belief long enough to interact effectively and successfully within the virtual world.

The feeling of “presence” is therefore important when considering emerging technologies such as VR, simulation rides, home theater, 3-D IMAX films, state-of-the-art video conferencing and computers that “talk”. An important differentiating characteristic of VR systems, compared with other human-computer interfaces, is their ability to create the sense of being in the computer-generated environment (Kalawsky, 2000). Each medium, however, is different in a variety of ways but they are all designed to give the user a type of mediated experience that has never been possible before.

The feeling of presence can be diminished by the onset of nausea (see section on simulator sickness) with users of environments with a high field of view (FOV) experiencing more nausea than users with low FOV. (Seay, Krum, Hodges and Ribarsky, 2002). Females have a wider FOV than males (Czerwinski, Tan and Robertson, 2002) so they are disadvantaged from the start if their enjoyment of the environment and therefore their feeling of presence is hampered by nausea.

Lombard and Ditton, (1997) suggest that a diverse group of people are interested in presence. They want to know how to create it and how to use it effectively. What is also important is how presence mediates or generates a variety of responses. By reviewing relevant literature they found six interrelated but distinct conceptualisations of presence, which they explain in their paper. In summary they defined a mediated experience as being one that seems truly “natural,”

“immediate,” “direct,” and “real,” an experience that creates the impression that it is not mediated; creating for the user a strong sense of presence.

An important component of spatial cognition is the ability to visualise, to mentally manipulate images or as Kosslyn (1983) would describe it, visualisation is the personal process of internally perceiving the essence of an object, person, concept or process. There is however, more to visualisation than just simple imagery, as imagery consists of mental images that are produced by memory or imagination (Samuels And Samuels, 1975). Therefore the ability to visualise has the added bonus of generating physiological and emotional responses similar to that which is experienced during real-time perception, i.e. the fear experienced during a dream is just as “real” as though it were occurring in the real world (Osberg et al, (1999).

This level of immersion into the virtual experience can be likened to watching a play at the theatre. Coleridge noticed that in order to enjoy a play, we have to temporarily suspend our knowledge that it is pretend, even although it is obvious that a play on stage is not real life. We do this willingly, in order to experience other emotional responses as a result of viewing the action (Laurel, 1991). VR can potentially provide a similar environment. In Winn *et al's* study they found that boys reported higher levels of presence than girls did. This finding may therefore show a positive correlation between spatial ability, imagination and the feeling of presence i.e. the imagined experience of “being there”. The male advantage concerning the ability to “imagine” has been used to explain why, both historically and in the contemporary world, there are more male artists, authors,

songwriters etc than there are females. Spatial reasoning ability and the ability to imagine are both considered right hemisphere tasks. Meyers-Levy (1994) demonstrated that right hemisphere functions include non-verbal production, visual activity, and visual spatial processing. The superiority of males in these tasks indicates that males are right hemisphere dependent. Chapter four will cover hemispheric specialisation and sex differences in greater detail.

1.1.2 Comprehension Of Science

Osberg, Winn, Rose, Hollander and Hoffman (1997) looked at the effect of having grade seven, learning impaired, students construct virtual environments on their comprehension of science. She advised “the concept of learning through virtual reality has proven to be of positive value in some instances...especially for lower-functioning male students.” (pg.3) Using Constructivist educational techniques, Osberg *et al* believe that VR translates otherwise book-learned information into a visual representation, which adds an additional element to a students knowledge base. They explain the richness of the VR experience in that it arises from the

“cognitive process that includes mental rehearsal, introspection, and visualisation, and distinguishes itself as a thought process different from verbal thinking whereby each exposure to the visual image permits the observer to become a keener interpreter of the visual display, i.e. to see more and more element within the display over time.”(Pg.4)

Why learning through VR should be more effective on lower functioning males than females is an important factor to consider and one that this present research may help to illuminate.

1.1.3 Learning Styles

Chris Byrne's (1993) research concerning VR and education, found that males were not only significantly less aware of the physical world than females when immersed in a virtual world but also that there were differences in learning strategies. He stated that different people take in information differently. He cited Browne (1990) when discussing the different learning styles of people described as right or left brain thinkers.

"Meanings for the right hemisphere dominant learner, however, are much more self-centered. They are more concrete, tied to visual and tactile symbols. Meanings for words are not abstract from personal context. They have meanings specific to certain contexts. While left hemisphere dominant learners can use words with precision to communicate meaning, right hemisphere dominant learners have difficulty because meaning is embedded in their holistic experience. Conveying specific meaning through language requires a separation from immediate personal experience in order to attach verbal symbols to that experience. The right hemisphere dominant learner, then, will have difficulty using language to express explicit meaning. The left hemisphere dominant learner attaches language to meaning in order to store them in memory. The right hemisphere learner probably stores meanings in pictures, impressions, without attaching verbal labels to them." (Browne, p. 29)

Subjects such as science and social science, that relies on the visualisation of abstract concepts, again a spatial reasoning skill and arguably right brained, can benefit from the use of VR. Byrne suggested that VR could be an effective tool within a classroom setting whereby the student can learn from either creating or exploring the virtual world, depending on their needs.

His research looked at the interaction between new computer technology and education and he believes that VR can help students to understand complex data particularly in subjects such as the sciences. By presenting complex information in a three dimensional format the student can enter into a VR world and interact

accordingly without the jargon that tends to be associated with complex subjects. Byrne used the example of a chemistry world where students can observe how electrons hover around a nucleus depending on the amount of energy involved. He explained that in the electron world the colour of the world could represent the amount of energy in the system with red representing more energy than blue. This method would enable the students to relate to hot things as being red and cold things as being blue thereby eliminating more complex concepts of joules.

VR therefore accommodates those students who are perhaps more likely to be concrete learners, that is, according to Kolb (as cited in Riding and Rayner, 1998) learners who respond primarily to kinaesthetic qualities of the immediate experience. Interestingly, as Byrne and his colleagues allowed children to create their own VR worlds, they found that there was a difference in learning styles with regards to the girls and boys. Girls tended to make abstract shapes with lots of colour while the boys concentrated on making robots or at least more complicated, concrete objects. They also had to reconsider what was appropriate computer behaviour, depending on the different learning styles being used. Byrnes observed that the boys tended to stay on task and worked quietly on their computers whilst the girls on the other hand, while working on the computer, also made up songs and dances or would get out of their chairs to spin around and giggle in between creating objects showing that social interaction is an important aspect of learning for girls. A study by Mills and Noyes (1999) suggested that it is differing learning styles and preferences that might be the cause of poor performance for many users of VR.

Interestingly, as mentioned earlier, the only significant difference between the performance of the girls and boys related to a feeling of presence, in that the boys in Byrnes' experiment were less aware of the physical world than were the girls. Race however, showed significant differences on a number of issues including "How much did you enjoy designing and building a virtual world?" "How much would you like to be in VR again" and "How much would you like to build another world?" These results showed that those students who were from "under-represented racial groups" did not enjoy the experience of working with VR as much as their white colleagues. This finding suggests an environmental influence on behaviour and performance and is an interesting research topic in itself.

1.1.4 Mental Rotation

Buckwalter, Rizzo, Van der Zaag, Van Rooyen, Larson and Thiebaut. M (1999) believe that being able to measure spatial performance may provide very important information concerning the diagnosis of pathological conditions such as dementia, particularly amongst an aging population. Using tests of spatial rotation ability administered within a VE is, in their opinion, a superior method of assessing spatial cognition than the standard paper and pencil tests. Mental rotation ability is the ability to orient objects spatially in ones mind and consistently shows a gender difference, favouring males. They conducted mental rotation tasks, both in V.R. (desktop) and paper and pencil form.

Wearing shutterglasses in the VR condition, the participants were able to manipulate computerised three-dimensional blocks, similar to the ones they saw in the paper and pencil test, by using a hand control the size of a tennis ball. Their

results confirmed the reported gender differences in that the males performed significantly better than the females in their paper and pencil test but in the VR test there was no gender differences. Women, they explained were able to see and manipulate three-dimensional objects as efficiently and as quickly as men do however, when performing the paper and pencil version of the test, women found it difficult to visualise the same process. Larson (1999) explained the lack of gender differences on the VE task as being because:

“rotation ability within a VE adds the appearance of real three-dimensionality to the stimuli. No longer do subjects have to perceive 2D drawings of 3D objects, a factor that some have hypothesized underlies the gender difference. By using real models, there is no longer a need to derive 3D representations from 2D drawings.”

They go on to say that the most compelling explanation for the gender difference on mental rotation relates to the different hormonal environments of males and females. Chapter four will investigate the biological approach to sex differences followed by possible environmental reasons for gender differences in performance.

1.1.5 Transference Of Knowledge.

The transfer of spatial knowledge in VE training has also found robust gender differences in training effectiveness of VEs in favour of males. (Waller, Hunt and Knapp 1998, 1999). Training using a VE can only be successful if the knowledge or skills gained whilst in the virtual world can be transferred and applied to the

real world. Waller et al studied those applications whereby a crucial part of the transferable knowledge included the spatial properties of large-scale environments.

Their experiments used groups of participants trained in six different environments, no training, real world, map, VE desktop, VE immersive and VE long immersive. The participants were asked to apply route and configurational knowledge in a real-world maze. Results showed that female performance on virtually all tasks tended to be poorer than that of men with regards to spatial layout recall, orientation, time taken to complete tasks and bearings tasks. They found that women who were VE trained performed significantly worse than men in the VE condition.

Important to this present research, the women also performed significantly worse than women trained in the real world. However, those females who were trained in the real world environment performed almost as well as the males who were similarly trained. They suggested that an explanation for the differences might have had something to do with the evidence that males have more experience and report more comfort and confidence with video games and computers and not because of differences in the way spatial knowledge is acquired. Waller *et al* therefore did consider environmental reasons for differences in performance; this present study will seek to find further evidence to explain why the females performed less well in Waller's maze experiments.

1.1.6 Simulator/cyber Sickness

Massey and Drexler (1995) cited evidence suggesting that females experience more motion and simulator sickness (SS) than males. When studying SS among helicopter pilots trained using flight simulators, the female pilots reported sickness severity at more than twice the level of the male pilots. Amongst their complaints were symptoms of disorientation. Kennedy warns that as VR devices become more advanced and the feeling of “presence” is increased, females will continue to experience more side effects therefore VR research will have to control for SS as it is a potential confound to cognitive performance.

The phenomenon of simulator or cyber sickness is similar to the kind of motion sickness experienced when traveling in a car. One explanation given by Been-Lirn Duh, Parker and Furness (2001) is the sensory conflict theory in that spatial orientation and the perception of self-motion are derived from visual and vestibular signals. Participants suffer from SS when there is a disagreement between visual information and inertial information. In other words, in one case the participants sensory system perceives motion and in the other, that the participant is stationary. Such an experience could be had at an IMAX theatre where the observer has a strong experience of movement while they are in fact standing still.

Parker and Harm (1992) stated that mental rotation is important for efficient goal-directed locomotion as a person must orient in order to locomote efficiently. Mental rotation ability is important not only for competent function but also for the reduction of motion sickness.

Seay, Krum, Hodges and Ribarsky (2002) found that field of view (FOV) was the major determinant of SS with high FOV users reporting higher levels of nausea than those with lower FOV. They explained that the bright, rapid motion of the optical flow created by the side screens was hard to attenuate and that these stimuli proved uncomfortable to the users of the VE. It is already known that females have a wider field of view than do males (Czerwinski, Tan and Robertson 2002) so it is little surprising that there are greater incidences of SS amongst female users.

1.1.7 Navigating Strategies.

A further important gender difference, especially regarding VEs, that goes hand in hand with the differences in spatial ability is the different navigating strategies used by males and females. The differences in these strategies are often magnified when 2D and 3D virtual worlds are being designed (Waller, Knapp and Hunt, 1998) resulting in males outperforming females in computer-generated environments. Czerwinski, Tan and Robertson (2002) hypothesised that providing proper display parameters to support female navigation strategies would allow females to navigate VEs as effectively as males. Research suggests that males are more accurate when it comes to building conceptual models of a given information space due to their greater spatial abilities. (Waller et al 1998 and Astur, Ortiz and Sutherland ((1998). Czerwinski, Tan and Robertson (2002) found that providing a wider field of view on large displays was beneficial to females navigating within VEs. A wider field of view, they claim, offloads cognitive map assembly resources to perceptual processes. They go on to say that

providing wider fields of view on a large display means the cognitive task of building a mental model is no longer necessary and that landmark navigation, being the preferred navigating strategy of females, is optimised. VEs typically have restricted fields of view compared to the real environments and Scholl (1993) found that this interfered with spatial learning in the real world. Chapter three investigates the difference in navigating strategies with regards to landmark and surveyors knowledge of an environment and why such differences might have evolved.

1.1.8 Place Learning Ability.

A study by Astur, Ortiz and Sutherland (1998) used a computerised version of the Morris water task as a means of measuring the place learning ability of males and females. The standard Morris water task is used with non-humans. In the virtual task, human participants were placed in a circular pool in a room with various distal cues, but no local cues. It was the role of the participants to escape from the water as quickly as possible by locating a submerged platform. Each participant was given a total of 20 trials with four different entry locations. Astur *et al* found significant gender differences in that the males were far faster at locating the platform. Those with the poor performances used inefficient strategies that involved indirect or circuitous paths (see chapter four). Further, they said that sex predicted spatial performance over and above that predicted by computer game experience thereby stating a clear biological as opposed to environmental difference between the sexes.

1.1.9. Transference of Spatial Knowledge.

Research by Waller, Knapp and Hunt (1998) looked at spatial knowledge that has been acquired in a V.E. The aim of their investigation was to address the degree to which measuring spatial knowledge in a V.E. adequately predicted subsequent performance in the real world. This is, of course, important to know when considering V.E. for training applications.

Their results showed that an individuals' ability to point to an unseen object in a V.E. was predictive of their ability to do so in the real world. Gender significantly influenced the accuracy with which participants made their pointing judgements with males being more accurate. They found that females became severely disorientated in their virtual maze with half of their female participants making bearing (pointing) errors in excess of 40 degrees for both the virtual and transfer phases of the experiment. None of the male participants had equivalent bearing errors.

Interestingly, Waller mentioned that there was a marked difference in estimating directions depending on whether a joystick or finger was being used for pointing. In the VE condition women on average erred about 67 degrees whilst using the joystick and only 43 degrees when using their finger to point when in the real world situation. This finding may show that apart from gender factors, interface proficiency also has to be considered before using measurements acquired in a V.E. to draw conclusions about peoples knowledge of a real-world space.

1.2. What Has Been Done About Gender/Sex Differences?

It has to be noticed that the above-mentioned differences are often treated as incidental findings and not of any great importance to the particular line of research being carried out at the time. As VR is being used more and more for potential employment assessment, training and for educational purposes, then a medium that is, all be it unintentionally, biased towards a particular gender is heading for trouble. It should be noted, that of all the research reviewed for this thesis, only one attempted to find an actual and effective way to level the playing field with regards to such differences (Czerwinski, Tan and Robertson, 2000).

The work of Czerwinski *et al* has gone some way to address the problem of different navigating strategies and the design of both 2D and 3D virtual worlds. Increasing the size of the display, in this case a 36inch “Artacus” display and by widening the field of view to 75 degrees, Czerwinski found that female navigation performance increased to the point where it was indistinguishable from male performance and did not have a detrimental effect on male performance. This shows clearly that sex and gender differences have been recognised but little has been done to pin point the root of the differences. Known real world differences are usually cited but little has been done to compare these differences to those found in VR.

The purpose of the research reported here was to investigate these differences in an attempt to understand whether or not they are due to environmental factors such as lack of practice, motivation and self-perception or if indeed the differences are due to innate biologically determined differences in spatial ability.

In order to answer these questions, supplementary but inter-related issues will have to be considered, namely:

1.2.1 Spatial ability.

Mental rotation tests (MRT) will be used to measure spatial ability as these have been shown to produce consistent and robust differences between males and females whilst other measures of spatial ability show no such differences or differences that are negligible. Chapter two will present a literature review regarding the definition of spatial ability, gender/sex differences found and the justification for using MRTs as a measurement for spatial ability.

A standard paper and pencil test will be used in the form of the Purdue Visualisation of Rotations, which is used, among other things, to measure the spatial ability of engineering and science students in American Universities. Two further computer generated MRTs (wire-frame and solid) will be used whereby the participants will view the 3D shapes via shutterglasses. The purpose of this exercise will be to see if performance on the paper and pencil test can predict performance in the 3D tests. Performance in the MRTs refers to speed and accuracy.

1.2.2 Navigation skills

Research into VR has suggested that differences in male and female performance within VR are due to females having a poorer innate ability to mentally rotate objects in their “minds eye” and that this ability underpins the ability to navigate successfully both a three-dimensional computer generated world and the real

world. Chapter three will give a clear and concise meaning to navigation and explain where the differences in male and female performances arise. Participants in this present study will be asked to explore a virtual environment; they will then be timed on a number of way-finding scenarios requiring them to reach targets using the most direct route. After their VR experience, the participants will be tested on their knowledge learned within the VE in that they will be asked to draw an accurate layout of the environment, state the number of landmarks used for navigating and recall alternative routes to a target criterion. A test of orientation ability will involve the participant having to visualise themselves in the VE before being able to answer location or object identification questions. Performance on the VE tests will be correlated with MRT performance.

1.2.3 Gender/Sex Differences.

Chapter four will clarify the distinction between gender and sex differences as the terms are generally used interchangeably throughout the literature. The distinction is important when deciding whether or not differences in performance can be rectified. Those differences pertaining to spatial ability will be discussed in detail in terms of the biological approach to sex differences and the social approach to gender differences in performance. If a difference can be shown to be a biological difference between the sexes then little can be done with regards to the individual however the VE system could perhaps be altered in order to accommodate individual differences. If a difference can be recognised as being due to environmental differences then training practice can be altered to accommodate the different learning experiences of the user or trainee.

The effects of gender/sex will be examined in both the MRT and VE tests. Other factors that may have an effect on performance will also be examined i.e. the faculty that the participants belong to, namely the Arts and Social Sciences or Science and Engineering.

1.2.4. The Relevance Of This Present Research

The purpose of this study is to investigate the findings that there is a significant gender/sex difference, favouring males, in mental rotation tasks and to ascertain whether or not spatial ability is an accurate predictor of performance within a Virtual Environment. The justification for such research lies in contemporary research into performance within VR that shows that there are significant differences, favouring males.

A sub-component of spatial visualisation is mental rotation and mental transformation and according to the cognitive literature of the 1970s, males have the greater spatial/quantitative aptitude. However, in a recent review, differences in spatial aptitude were found to have either disappeared or were negligible except for mental rotation which still shows a consistently large and reliable difference, favouring males. It is this very ability to visualise objects in space that some researchers believe underlies the gender differences in quantitative aptitude and achievement (Norman 1990). Mental rotation will therefore be used to measure spatial ability and performance on the tests will be correlated with navigational performance in a virtual environment. Social factors such as motivation, experience and self-perception will also be considered.

1.2.5. The Importance Of This Research.

Computer-simulated environments are proving to be a successful medium for training individuals about real-world spaces. Successful performance within VR involves space perception, navigational skills, tracking, cognitive-map development and maintenance, distance perception and spatial knowledge representation techniques. Individuals, however, perform differently when interacting with VR and there is some research being carried out on the role of user characteristics and abilities that can determine whether or not training spatial knowledge in a virtual environment is effective. Individual differences are a major source of variation in performance whether it is a real-world spatial task or one carried out in a computer-generated world.

Gender/sex differences in performance are also an important source of variation but one that is receiving little or no attention. The very fact that the term gender and sex are used interchangeably indicates that those carrying out VR research are often unaware of such fundamental differences. Understanding these differences could clarify whether spatial skills can be trained in order to level the playing field or if interfaces have to be designed to accommodate individual differences.

Very often it is the male superiority argument concerning spatial abilities that is once again being used as a means of explanation for sex differences. Should it be the case that the innate differences that lie between males and females are reinforced both socially and culturally throughout our life span, then it should be possible for females to perform as well as males when it comes to spatial skills if given relevant motivation, reinforcement and experience. This hypothesis is

supported when comparing results found in the early seventies, to recent results, which indicate that, with a change in societal attitude to education and upbringing, females have quickly caught up with and often overtaken, in areas of male dominance such as mathematics (See chapter four for a fuller explanation)

It is the intention of this present research to investigate performance by testing participants on MRTs, both real-world and virtual, to see if their performance within VR rests upon this very distinct aspect of intellectual functioning. Environmental factors, which have not been considered previously, will also be manipulated to see if there is an effect on performance.

The results gleaned from this study may well lead to a basis of knowledge from which further research can grow. Should the findings show that the differences are more innate than learned, or vice versa, is immaterial? What is important is understanding the underlying processes that cause differences in performance and whether or not they can be rectified either by effective training strategies or by using more carefully designed interfaces or indeed a combination of both.

1.3 How The Study Was Carried Out.

An experimental approach to the research question was identified as being the most effective means of investigation, providing a rich source of data. Quota and opportunity sampling were used all participants were either students or faculty members who fell into either the Arts and Social Sciences or Science and Engineering Departments. All of the participants were drawn from Dundee University, Abertay University and Dundee College. All were right handed.

Participants were paid five pounds for completing the mental rotation tasks only, ten pounds was paid to those participants who completed the MRTs and then returned to complete the VR investigation. In the motivation experiment there was a “prize” of one hundred pounds offered as an incentive to win. Further information was gathered from the participants by using a self-report questionnaire.

1.3.1 Mental Rotation Tests.

For this study, three phases of testing were administered. The first phase consisted of mental rotation tests. Mental rotation tests were used because, as discussed in chapter three, they consistently produce a robust gender/sex difference.

Six, independent measures, MRTs in total were used:

Purdue Visualisation of Rotations test (ROT) which is a paper and pencil test.
(See Fig.5.2)

3D “wire-frame” MRT viewed via shutterglasses. This test used Shepard and Metzler style, line drawing shapes that are enhanced through the use of three-dimensionality (see Fig.1.2. for an example).

3D “solid” MRT viewed via shutterglasses. The shapes are as above however, they are more concrete shapes as the wire frame has been removed and replaced with shading. By removing the wire frame the illusion of perspective, an

important cue to depth was also removed to a degree. The solid shape is a more complex shape to mentally manipulate. (See Fig. 5.9 for an example).

The ROT was also used to test participants when investigating the effect of self-perception on performance. There were three conditions

- Participants were informed that males outperform females on MRTs
- Participants were informed that females outperform males on MRTs
- Control group, participants were just asked to do the test.

The “solid” MRT was converted to a paper and pencil test and used to investigate the effect of practice on performance. Participants were tested using three tests consisting of 20 different pairs of stimuli each, given a number of days apart.

The “wire-frame” 3D MRT was used to investigate the effect of motivation on performance. There were two conditions:

- Participants were entered into a competition where the person who was judged to be the fastest and most accurate at completing the MRT would win £100.
- Participants were merely asked to complete the MRT.

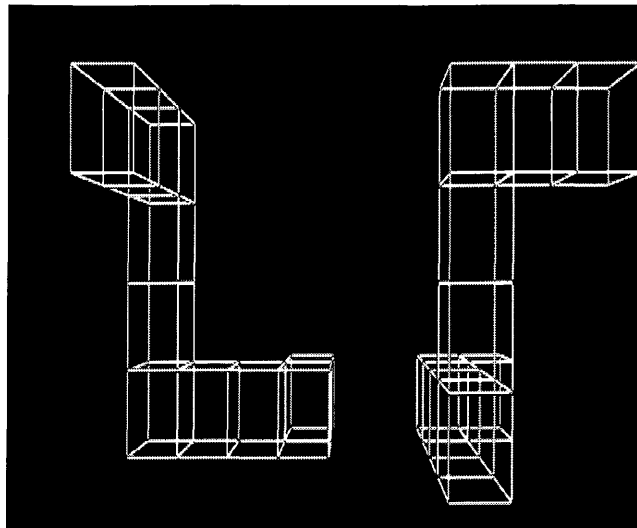


Fig.1.2 shows one example from the “wire-frame” Mental Rotation Test.

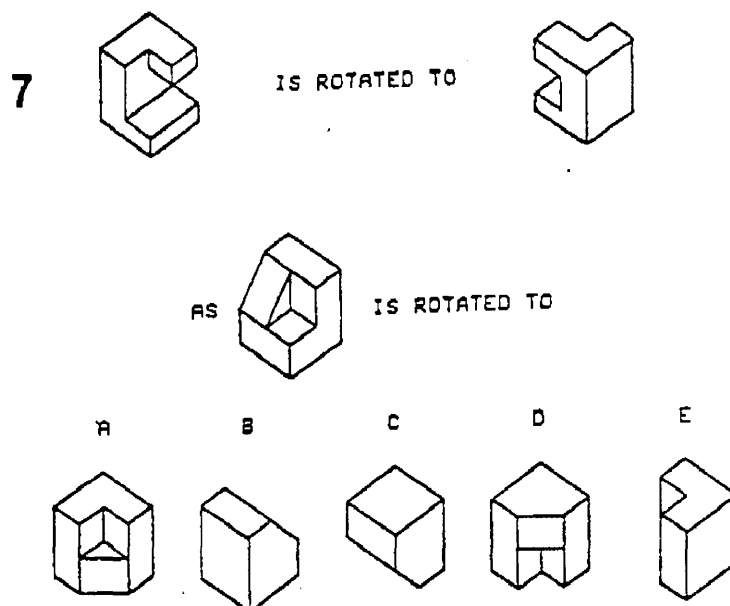


Fig.1.3 shows an example from the Purdue visualisation of rotation test. (Permission from G.Bodner, Purdue University)

1.3.2. Virtual Reality Phase Of Testing.

In the third phase of experiments a repeated measures test was carried out, using the “wire-frame” and “solid” 3D MRTs. The ROT was used to compare the participants accuracy performance with that on the 3D tests. The ROT is a timed

test (10 minutes) whereas the 3D tests are not, the participants were merely requested to complete the test as quickly and as accurately as possible.

The VR component used a computer game entitled SWAT, adapted for 3D use. Participants viewed the environment via shutterglasses creating the illusion of depth perception. This was not a fully immersive experience.

SWAT was chosen as it offered the use of a large but familiar environment, namely a house (see Fig 1.4 and 1.5). A house was believed by the author to be neither a male or female orientated environment. Both would be familiar with a house therefore the environment itself would not bias. To enhance neutrality, the house was particularly sparse, devoid of “female” characteristics such as flowery wallpaper or cosmetics etc. The house was also on three levels, one of which was at a different orientation from the other two. The back garden and pool area could not be accessed from the front garden; in other words, the participants could not simply navigate to the rear quarters by following an already provided path. There were 18 rooms, which included bathrooms, utility rooms, dressing rooms etc and three flights of stairs. To further complicate matters, there were 24 doors to negotiate. It is the authors belief that the house was as complex as any maze that other researchers tend to favour, the difference being that the former is commonplace in the real world whereas the latter is not, except as a form of problem solving entertainment. This very fact may in itself have some bearing on performance.



Fig. 1.4 shows part of the interior of the virtual house, this example shows the view from the sitting room onto the swimming pool.

The VR testing comprised of 6 stages.

- Participants explored a virtual environment for fifteen minutes.
- They were tested on their navigation skills as they were timed on the length of time it took them to complete five way-finding scenarios.
- They were asked to recall and draw a plan of the environment requiring memory and orientation skills.
- They were tested on their visualisation and route learning skills.
- They were asked to recall the number of landmarks they used for aiding navigation.
- They were tested on their visualisation and orientation skills.



Fig. 1.5 shows the interior of the virtual house, looking from the front door, through the lounge to the kitchen at the rear. To the left can be seen the passage leading to the stairs, also a door to a bathroom and beyond that, open doors to the sitting room shown in Fig.1.4

Performances on the MRTs were correlated with performance on the VR tasks to see if spatial ability, i.e. mental rotation ability, is indeed a cognitive function that underlies navigation ability. Gender/sex performance will be the primary focus although Faculty and Age will be factors considered as will information taken from the questionnaires, such as prior computer experience and maths ability.

1.3.3 General Layout.

Now that a general overview of the study has been provided, it is appropriate to review the research literature pertaining to this area of investigation. The author will begin with chapter two explaining what is known about spatial ability and mental rotation and why it is important to navigation whether it be in a real or virtual world. Chapter three will continue by explaining how human beings

perceive and navigate a three dimensional world. Chapter four will define gender and sex differences and what these differences are in relation to spatial ability and navigation. The thesis will go on to describe in detail the methods used to conduct the three phases of experiments and their results. The penultimate chapter will discuss the findings and finally, the last chapter will return to the literature reviewed in this chapter to see if fresh interpretations can be put on the results found by the cited researchers by including the conclusions drawn from this study and further works cited throughout the following chapters. Future research issues and topics will also be considered.

1.4 In Summary.

This chapter has highlighted the fact that there are gender/sex differences in performance with regards to VR, in that males outperform females on mental rotation tests and the ability to transfer knowledge, particularly spatial knowledge, from a VE to the real world. There are also differences in learning styles, navigating strategies and place learning abilities. Finally, the research shows that females are more susceptible to simulator sickness and yet less likely to experience the feeling of presence. Reasons for the differences range from biological or hormonal differences to lack of computer experience. Therefore, the main question that this study will address is whether the differences found in performance within VR are due purely to innate spatial ability differences or due to, at least in part, environmental factors and what can be done about such individual differences.

Chapter Two

Mental Rotation

Introduction:

This chapter will deal exclusively with mental rotation as it is an important component of spatial ability and fundamental to performance within the world, whether it is virtual or real. The first topic to be looked at will be a brief history of the study of spatial cognition along with definitions of spatial abilities. This information will create a context in which to discuss mental rotation, which is the ability to visualise or imagine an object in ones “minds eye” and mentally rotate it. This ability is crucial to learning with a VR and the transference of spatial knowledge to a real world situation.

Quite how we can imagine or see pictures in our head will be discussed with reference to the imagery debate that has been on going between researchers such as Kosslyn and Pylyshyn for some decades but has puzzled philosophers for centuries. Whether we use analytical or analogue processes or indeed a combination of both may throw some light on the different ways in which the male and female or novice and expert make mental representations. Practical applications of imagery and mental rotation will be discussed as will new research using the aid of functional Magnetic Resonance Imaging (fMRI). Final sections will relate to the gender/sex differences found in mental rotation ability and how some researchers have found ways to overcome the differences. That the differences have been overcome in these studies emphasises the importance of

environmental influences regarding gender/sex differences in cognitive abilities, a primary issue in this present study.

2.1 Brief History Of Spatial Testing.

Before discussing mental rotation, it would first be necessary to discuss spatial ability or spatial intelligence, as it is sometimes called. The term spatial intelligence has inherited a plethora of definitions, along with arguments concerning its significance and even its existence.

The history of the study of spatial intelligence primarily began at the beginning of the 20th Century however its origins could be traced back to the Binet-Simon Scales of Intelligence tests which attempted to measure practical ability. These tests came at a time when psychologists were questioning the belief that academic success was dependent upon the ability to read and write. The type of question being asked concerned the relationship between verbal and non-verbal tests and indeed, was there any relationship between non-verbal tests and intelligence.

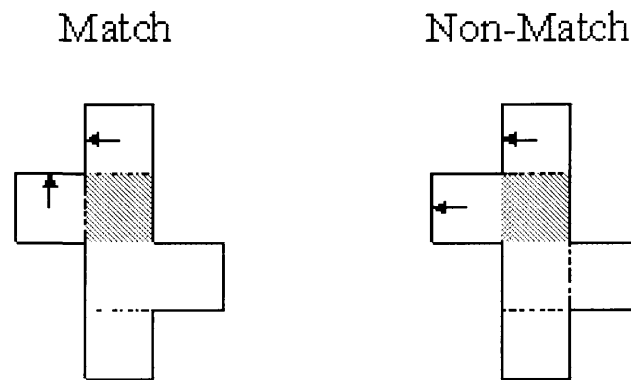
In the thirties, Thurstone's work (Sternberg, 1994) at this time argued that human intelligence was composed of several independent factors of specific abilities and not just one general ability factor. His primary mental abilities consisted of verbal comprehension, word fluency, number facility, spatial visualisation, associative memory, perceptual speed and reasoning. His multiple factors theory was and is used to construct intelligence tests that produce a profile of the individuals' performance on each of the ability tests rather than a general intelligence test with a single score i.e. IQ. One of the specific abilities he identified was "space"

which he stated required the ability to hold a mental image, mentally twist, turn and rotate it into different positions and then be able to match the transformed image with a suggested solution. This definition became one of the first to credibly describe spatial ability.

Researchers in America, who were attempting to put together a means of accurately testing spatial ability in potential air pilots during World War 2, built on the work of Thurstone. The tests that resulted from their research were used to give evidence of sub-factors of spatial intelligence, principal among which was the notion of the ability to visualise. Spatial relations were thought to be the ability to determine the relationship between different spatially arranged stimuli and responses, and the comprehension of the arrangement of elements within a visual stimulus display. Visualisation, on the other hand, was defined as the ability to imagine the rotation of depicted objects such as folded and unfolded flat patterns (see Fig 3.1) and the relative changes of positions of objects in space (Guilford and Lacey, 1947).

The 1960s onwards showed a shift in emphasis from attempting to define the nature of spatial intelligence to examining the sources of variance in spatial ability such as sex related differences in performance on spatial tests. By 1971, Guilford devised his CFT tests, which stood for Cognitive operations, Figural content and Transformation product, otherwise a block rotation test. There were variations on this theme but mostly spatial ability was defined as a combination of factors. Wattanawaha (1977) believed that in order to successfully solve a spatial task an individual had to use certain mechanisms to deal with four distinct aspects of the

problem. Those aspects concerned the dimensionality of the problem, internalisation i.e. is the imagery static or dynamic, the manner of presentation of the question and finally, the thinking required to arrive at a solution.



Participants in the paper folding test are required to respond whether the arrows would meet when the object was folded.

Fig.2.1. Visualisation was defined as the ability to imagine the rotation of depicted objects such as folded and unfolded flat patterns as can be seen in this example of a paper-folding test.

Lohman (1979) conducted a complete reanalysis of all available data to conclude that there were three major and several minor spatial factors. Interesting conclusions of his work are that visualisation, one of the major sub-factors was the most difficult and that the minor factors pertained to performance factors such as speed and memory.

The last 20 years has been characterised by new technology that has been introduced into the world of spatial intelligence. Pencil and paper and model based systems of testing are being replaced by 3D computer based methods and

this present research used the more recent form of testing medium, that of virtual reality.

2.2 Spatial Ability:

Central to this form of intelligence are the abilities to perceive the visual world accurately, the ability to encode visual stimuli and to perform transformations and modifications upon initial perceptions, in other words, mental manipulation. A further necessity is the ability to recreate aspects of a visual experience, even in the absence of the relevant physical stimuli.

A spatial ability is our innate ability to visualise without the need for any formal training, whilst spatial skill refers to skills that have to be learned. There are many interpretations of the term spatial visualisation skills; however, five components have been listed as constituting spatial skills. These categories consist of spatial perception, spatial visualisation, mental rotations, spatial relations and spatial orientation. Mental rotation requires the entire object to be mentally transformed by rotating it in space whereas mental transformation means that only a part of the object is transformed.

A more recent large-scale meta-analysis into spatial abilities (Voyer, Voyer and Bryden, 1995) stated that there are three types of spatial ability: spatial perception, mental rotation and spatial visualisation. Spatial perception is defined as being the ability to ignore distracting information and identifying spatial relations. It also involves the ability to perceive the location of something vertically and or horizontally. Mental rotation is the ability to rotate two and three-dimensional

objects, quickly and accurately, in the imagination. Finally, spatial visualisation is the ability to produce the correct solution when given complex spatial information, that requires taking several steps to solve. According to Norman (1990) a persons spatial skill level is the most significant predictor of success in their ability to interact with and take advantage, of the computer interface.

2.2.1 Spatial Cognition

Spatial cognition is fundamental for general cognition and is an important component in cognitive development as it is the process by which we perceive, store, recall, create, edit and communicate about spatial images. With this ability we are able to create meaning by manipulating images of the world that exist either in our minds or in the world in which we exist. A spatial cognition disability may lead to difficulties in education and indeed to every day life.

According to Gardner (1993) spatial ability and spatial cognition are needed for higher level thinking skills such as language however, intelligence he believed, was more than language and mathematical skills. He also believed there are several different intelligences that should be valued and nurtured, these consisted of linguistic, logical-mathematical, spatial, music, interpersonal and intrapersonal intelligences as well as bodily-kinaesthetic ability. Gardner believed that in an ideal school there should be two foundational principles; the first is that all people have the same interests and abilities; and not all learn in the same way.

Osberg, Winn, Rose, Hollander and Hoffman (1997) used VR as a tool for enhancing spatial processing skills in children who are neurologically impaired. In particular they are interested in:

Spatial relations, which is defined as an understanding about the relationship between objects in space, both in dynamic and static environments.

Sequencing, being the order of both objects and events. Primarily this relates to the conservation of order, especially when the orientation of an object or set of objects changes.

Classification is the ability to understand the relationships that exist between objects and to be able to create meaningful groupings, therefore creating mental order.

Transformation is the ability to mentally transmute an object from one state to another without the need for physical representation of the transformation.

Rotation of objects in space whilst maintaining orientation and attributes during transition.

Whole-to-part relationships: construct and deconstruct complex objects, enabling understanding at both the micro and macro level.

Visualisation is the ability to construct, manipulate and interpret images in the mind.

Creative problem solving is the ability to put together all of the above whilst applying logic.

It can be seen that spatial ability and spatial skills are of primary importance not only to the understanding of the world but also to its navigation.

2.3 The Importance Of Mental Rotation.

Everyday life events require this imaginal visio-spatial transformation ability. The ability to mentally rotate is required for such activities as making judgements when driving a car, finding the most economical way of storing items in a limited space, finding your way back to the car when parked in a novel car park in a novel town, taking part in sports activities or moving furniture through a narrow doorway. All of these events require visualisation skills in order to picture movements of locations of physical items in a 3D space. Such a mental image or mental representation of stimuli or events that are not physically present is reconstructed from long-term memory stores.

Kimura (1992) suggested that some factor of imaginal rotation ability might be a significant component of route learning with such tasks generally showing large sex differences favouring males. She suggested that rotation is an ability that is separable from other spatial abilities.

The easiest and standard way to describe mental rotation is to set an individual a cognitive task, such as counting how many windows are in their house or flat. In order to reply, the individual usually states that they recall a mental map or image of their home and mentally travels through the map as they count the windows as though they are actually walking around their house. Such a mental image or mental representation of stimuli or events that are not physically present is reconstructed from long-term memory stores. There are four main characteristics of mental rotation:

Generation - The reconstruction from long-term memory

Retention – Images are retained in short-term memory

Inspection – Generated images can be “scanned” by the “minds eye” and the time necessary to scan between imagined objects correlates with the distance between those objects on a physical map.

Transformation – Mental images can be manipulated in the same way as real objects and the duration of time needed to perform mental rotations is comparable to the time needed to physically rotate the actual objects.

2.3.1 Shepard And Metzler’s Study Of Mental Rotation.

When looking around the world we rarely see the whole of any object and yet we do not get the sense of being in an incomplete world. Our visual system fills in those parts of the objects that are non-visible. Vision is the most powerful sensory modality. With only a few exceptions, most objects can be recognised even when they are upside down and presented in unusual orientations. Visualisation is when we can mentally “picture” and manipulate these same objects even when they are no longer physically present.

Shepard and Metzler’s (1971) study of mental rotation is often used to support the view that the mental representation of spatial information is in the form of mental images which can be manipulated and scanned as we would a real visual object. They used mental chronometry, which is the precise timing of a particular cognitive activity, to investigate the nature of mental representations of objects. Their study looked at the way in which humans are usually able to determine that

two, two-dimensional pictures portray objects of the same three-dimensional shape even although the objects are seen in differing orientations (see Fig.2.2).

Participants in their study were presented with a number of images representing pairs of objects. The pairs were viewed from the same direction in 3-D space but different pairs had different viewing directions or orientations. One of the object pairs was rotated by an angle ranging from between 0 degrees and 180 degrees with respect to the other object.

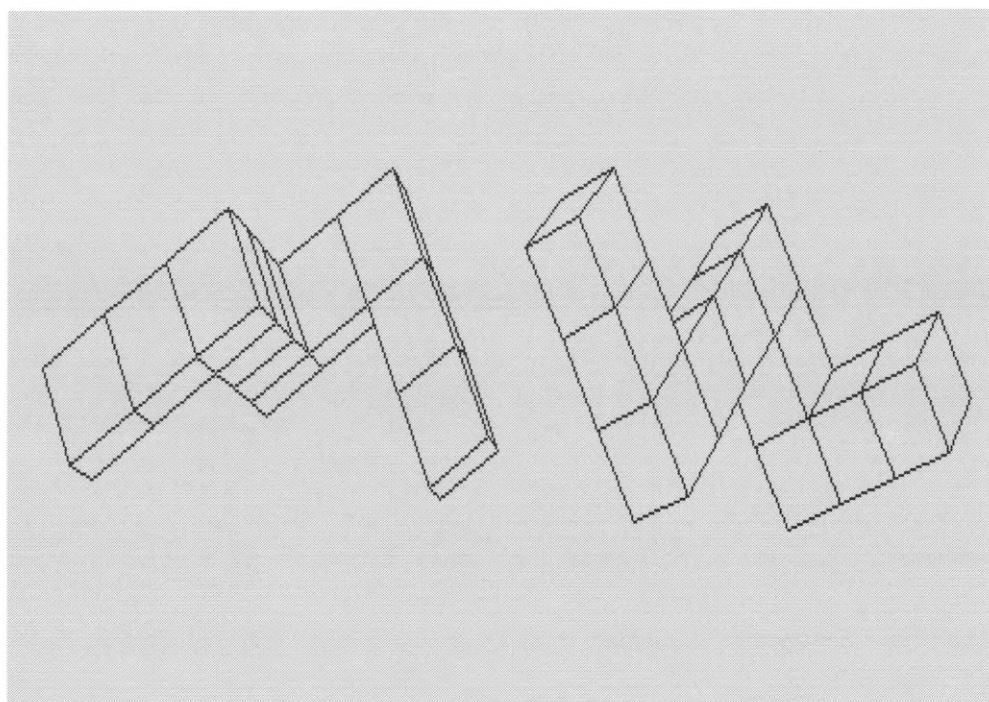


Fig 2.2. A pair of stimuli from a Shepard and Metzler style mental rotation test.

A “same” pair consisted of two images, which could be rotated into congruence with each other. A mirror image (or the 3D equivalent called enantiomorphs) or “different” pair consisted of two images, which could not be rotated into congruence with each other. Participants had to compare the two images of a pair

and decide whether they were of the same object or different objects. The difference in angle was produced by manipulating the rotation i.e. A) a two-dimensional rotation or rotation of picture plane B) a more complex depth rotation or rotation of the object into the picture.

In orientation judgment tasks, objects are mentally rotated around their own axes in a process analogous to transformations in the physical world. Shepard and Metzler found that the time it took to make same or different judgements on two pictorial stimuli viewed at different angles was influenced by the extent to which the two shapes are rotated relative to each other. It was found that the greater the angle, the longer the reaction time was to make the judgements i.e. every 60 degrees of physical rotation required one second of mental rotation before participants responded, suggesting that the rate of mental rotation is at a constant velocity.

The choice of shapes in their study was important in that the perspective drawings were all relatively unfamiliar and meaningless. They ensured that the choice of objects that were isomers of each other in the “different” category could not be “worked out” by the participants because of a distinctive feature possessed by only one of the two objects. If there had been a distinctive feature then it would be possible for the participant to reach a conclusion of congruence without the need to carry out a mental rotation operation.

Shepard and Metzler had therefore found that there was a linear relationship between the relative angle of rotation between the two objects and the time

required making the “same” judgement. A figure that needed to be rotated 120 degrees to bring it back to the orientation of the first drawing took longer to judge than one needing only 60 degrees of rotation. More interestingly, they also found that reaction time was not any longer for a rotation in depth in comparison to the apparently simpler rotation in the picture plane. The finding that people require progressively more time for every additional amount that they must mentally rotate an object, suggested that "mentally rotating" objects is similar to physically rotating objects.

They asked their participants how they came about their decisions. The participants reported a subjective feeling of rotating the objects in their minds. In order to compare the two shapes they had to imagine one object rotated into the same orientation as the other and that “*they could carry out this “mental rotation” at no greater than a certain limiting rate*”. Shepard and Metzler believed that the participants were operating on 3D representations of the objects in both the plane and depth conditions and could therefore imagine the rotation around whichever axis was required, therefore supporting the view that a process of mental rotation was involved.

The experiments illustrated the idea that images are internal representations that "stand in for" or "represent" the corresponding objects, suggesting that participants actually perform mental rotations, which require the same amount of time proportional to physical rotations. They therefore argued that the participants were using mental imagery or an analogue representation and, arguably, not using knowledge that is represented propositionally.

Shepard and Metzler's studies addressed an intense debate that had begun in the early 1970s about what kind of representation imagery involved. The debate concerned whether mental images were *depictive* or *propositional* representations. A propositional representation is a verbal representation or a mental sentence that specifies meaning. A depictive representation is a type of picture that specifies the location of objects in space.

Results supporting an increase in reaction time to compare objects at increasing orientation suggested that mental imagery is a depictive or analogue representation, similar to the physical object. There are critics of the analogue processing theory and it will be necessary to look at the works of Pavio, Kosslyn and Pylyshyn in order to get a fuller understanding of the on-going debate. A clear understanding of the alternative explanations for mental imagery might give some indication that males and females use different representational processes, which is reflected in their performances.

2.3.2 The Imagery Debate.

Everyone experiences mental imagery but to differing extents. Some report that their images are detailed and almost photographic in quality while others would say their mental images are more like sketches of the real thing. Quite how we make internal mental representations has been the source of discussion and debate for many centuries but for the purposes of this present study, the imagery debate will primarily discuss the traditional symbolic view. How we experience mental imagery and how such images are "constructed" may reveal insight into the

differences that occur between males and females when it comes to visualisation, orientation and navigation skills.

A long-standing issue concerning visual imagery revolves around the extent to which an image may be said to be analogical or veridical in form. The fact that imagery exists is not disputed but the concept of “pictures in the head” is difficult for imagery theorists such as Kosslyn to get away from, as there is quite obviously no facility within the brain whereby a “picture” is projected upon a screen for inspection.

It was Locke’s Empiricism that had suggested that no thought was possible without images and the controversy raised was whether or not it was possible to have imageless thought. Today, however, the argument has changed, computational cognitivists hold that, as thought is computational, then its correct representational format is propositional and digital and not analogue.

These two theories are the main models that psychologists use to explain how visual stimuli are processed and then represented in memory. Psychologists such as Shepard and Metzler (1971) and Cooper and Podgorney (1976) proposed the analogue model while researchers such as Yuille and Steiger (1982) and Barfield, Sandford and Foley 1988 proposed the propositional model.

Paivio (1986) said that how we are able to mentally represent objects is probably the most difficult problem to solve out of all the sciences. An easy way to differentiate between the two theories is by considering the analogical representation as being a visual image whereas the propositional representation is

more abstract, language-like representations which is meant to capture the conceptual content of situations and things.” (Eysenck and Keane 1986, pg 204)

It should be remembered however, that the theories are not physiological in nature, and arguments for and against each theory is only useful for finding a reasonable model that helps the understanding of thought processes.

2.3.3 Pavio’s Dual Coding Model.

Pavio’s Dual Coding hypothesis (1971, 1979, 1983 and 1991) stated that long-term memory contains two distinct coding systems for representing information. The first is verbal, containing information about an items abstract, linguistic meaning and the second referring to analogue or mental picture representations.

He believed that a verbal system deals with all verbal information that is then stored in a verbal form. Along with this, he suggested that there is a non-verbal system that carries out image based processing and representations. Both of these systems are specialised for encoding, organising, storing and retrieving distinct types of information. The imagery system therefore processes non-verbal objects and events such as processing the spatial layout of a scene or generating a mental representation. On the other hand, the verbal system deals with all linguistic information and specialises in sequential processing, as is the serial nature of language.

Both the verbal and non-verbal systems are further divided into sensori-motor subsystems and deal with different types of information. With regards to vision,

the verbal system would deal with all visual words whereas the non-verbal system would deal with visual objects. In the case of the auditory sensori-motor subsystem, auditory words would be processed via the verbal system and environmental sounds via the non-verbal system. Haptic information such as writing patterns is verbal whilst the “feel” of objects is non-verbal.

Both systems have basic representational units termed *logogens* for the verbal system and *imagens* for the non-verbal system. These representational units are modality specific for each of the sensori-motor subsystems. Logogens are stored in the verbal system as discrete, sequential elements, resembling words and sentences. As an example, there may be a logogen for the word “dog”, and as logogens are modality specific, there will be a logogen for the spoken sound “dog” whereas there will also be a logogen for the visual form of the written word “d-o-g”. Imagens, on the other hand, are basic units that identify and represent images, in the different sensori-motor modalities; therefore, in the visual system “dog” will be represented by an image of a dog.

Referential processing refers to the cross-activation of the two types of memory codes. In the case of the word “dog”, initially the verbal memory code might be activated which in turn activates the corresponding imagen in the visual system and the image of a dog is produced. However, Rieber (1994) points out that the relations between the two systems are not always one-to-one, since an image has the potential of evoking many different verbal labels. *Associative processing* refers to activation of additional information within either system, hence, showing

a picture of a dog may invoke many different verbal responses, such as "animal," "dog," "collie," or "Rover."

The example of a single picture evoking many different verbal labels can be explained two ways. First, the different responses may be the result of multiple links between the single imagen of the visual system and the many logogens of each verbal representation. Second, it is possible that the image was linked *only* to the logogen corresponding to "my pet Rover," which, in turn set off a search strategy within the verbal system resulting in a response similar to "Rover is a collie, which is also a dog, which is also an animal." Associative processing therefore refers to the activation of informational units within either of the systems (see fig 2.3)

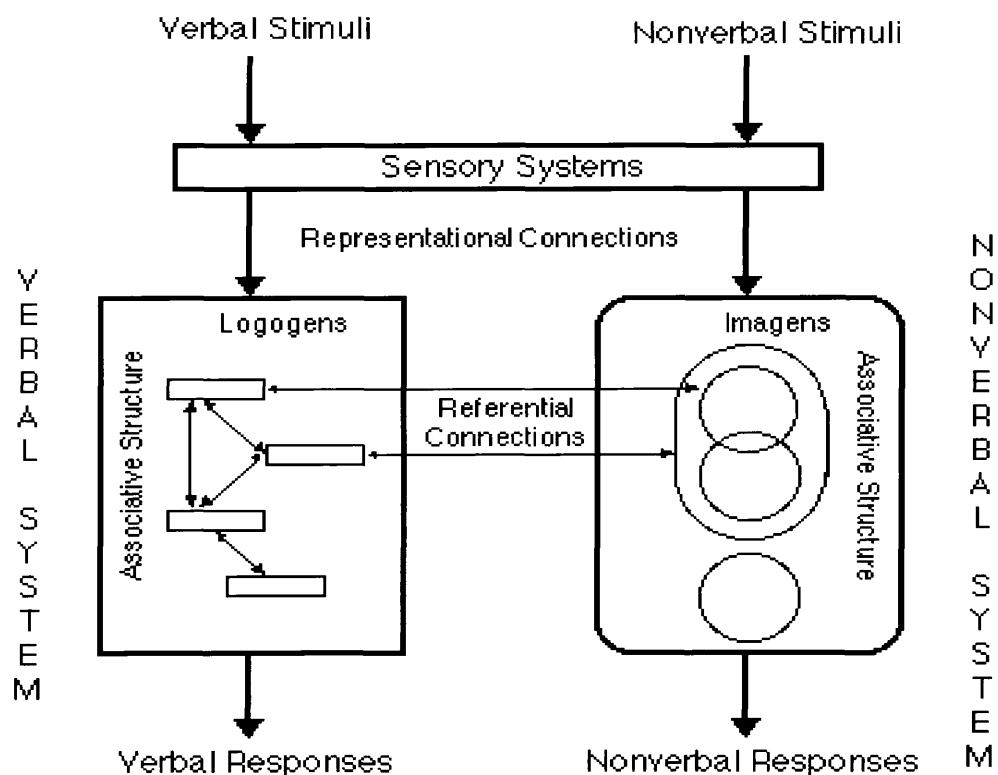


Figure 2.3. A dual coding model for memory and cognition (after Pavio, 1986).

Processing in the verbal system is believed to be sequential or linear, whereas processing in the visual system is thought to be parallel or synchronous. Both imply hierarchical organisations, but access from one logogen to another, versus one image to another, is qualitatively different. If you form a mental image of a dog, you can then "look" from one end of the dog to the other or indeed from its ears down to its toes. This ability to mentally scan an image can be accessed easily or quickly, regardless of which direction is taken. On the other hand, the ability to recall a particular line in a song requires a linear or sequential search from the beginning of the song to the end. Verbal information would therefore have to be stored in memory in a different way from visual information.

A major problem with Pavio's theory is that it says little about the structure of imagery. His theory does not inform us as to how we see images in "our minds eye" nor can it explain how we can scan, rotate or manipulate the images.

2.3.4 Kosslyn's Computational Model.

The analogue or imagery model states that the visual information that we take in from the environment is stored in memory as images that are very similar to the actual visual images that the retina receives. There is also a one-to-one correspondence between points on the real object and points on the mental representation of the object. (Cochrane, Pick and Pick, 1983) As a real object would be rotated so too would the mental representation. Therefore, just like the real object, a mental representation of an object or "pictures in the head" can be scanned, folded and rotated. Finke (1989) stated, "similar mechanisms in the visual system are activated when objects or events are imagined as when they are

the same objects or events are actively perceived". Put simply, analog code creates a mental picture or internal representation, which is a copy of the external stimulus. This picture is stored in memory much the same way as a computer stores a bitmap i.e. in binary code. Using a PET scan, Kosslyn (1993) showed that when his subjects were asked to carry out visual imagery tasks, the occipital visual cortex was activated as would happen when viewing the physically present object.

Kosslyn (1994), describes mental images as being unconscious and that they are specific data structures in the cognitive architecture of the mind, which play the role of "images" in mental computation. Pylyshyn (2001) describes cognitive architecture as being the set of properties of the mind that are fixed with respect to certain kinds of influences, therefore it cannot be altered by changes in an individual's knowledge, goals, fears, hopes or fantasies etc. In other words, when an individual learns new information or draws inferences from knowledge they already have, their cognitive architecture does not change.

Instead of trying to understand an image as being a type of experience that resembles perceptual experience, it might be better thought of as a type of cognitive process or underlying representation. (Kosslyn, 1983). These images are processed holistically, in such a manner as to preserve the qualities of the images and that their presence or activity can, but does not have to, be consciously experienced as imagery in the original sense.

Kosslyn's theory is a computational model and states that visual images are represented in a special, spatial medium. The medium that the object is to be presented can be likened to a television or computer screen, neither have real pictures inside them but they output pictures to cathode ray tube screens (depending on the age of your computer/television). A CRT screen is a matrix or array made up of cells that can be filled or unfilled. The information used to create the pictures on the screen can be encoded as a set of co-ordinates plus values such as fill cell at (023, 456). These co-ordinates or value lists are not in themselves spatial but are instead encoding spatial characteristics such as adjacency, distance and form. These spatial characteristics function as spatial representations if accessed in the right way, in other words, if co-ordinates corresponding to adjacent cells are accessed in sequence. Our brains are not like computers as they differ with regards to material, operation and organisation but it could be argued that they are functionally similar. (Jagard, 2001).

2.3.5 Kosslyn's Theory Mentions Four Properties Of The Medium.

The first is that it functions as a space, in that it preserves the spatial relations of the objects it represents. If, for instance, you are recalling a scene where a house is in the top left of the scene and a car is in the bottom right of the scene, these relations will be preserved in the spatial medium. The spatial medium has a boundary and therefore has limitations. If an image moves too far in any one direction, it will overflow the boundary. The central area of the medium has the highest resolution and Kosslyn depicts the shape of this area as being roughly circular however, it becomes more oblong at the periphery.

Images are therefore not represented in a uniform manner. Highest resolution is at the centre of the image, as would be found in the visual field, with the images becoming more vague or fuzzier as the image reaches the periphery. The spatial medium has a grain, rather like a photograph, that obscures details on small images. The grain refers to the size of the pixels or dots of colour that the image is constructed out of. Large dots minimise the amount of detail represented, whereas many small dots can produce far greater detail in a given image. The grain of the spatial medium will therefore dictate the clarity of the representation. If the grain is not detailed enough, as the representation is made smaller, parts of the image will disappear as it may well be represented by only a single pixel.

Once an image is generated on the spatial medium, it starts to fade. In order to keep the image in the medium it would have to be constantly refreshed. This can be compared to after-images that occur in the visual system. If an individual stares at bright lights and then looks away or closes their eyes, an after-image can be seen which has been caused by over stimulation of the retinal cells. These images are not the same as visual images but as in visual images, they begin to fade after they first appear.

According to Kosslyn's theory, we store image files that represent the co-ordinates of pixel like points in the spatial medium that can represent either an entire object or parts of it. *Skeletal images* depict basic shape or outline of an object but not its detail. *Propositional files* add the properties of the object, i.e. has four wheels, has two doors, to the relationships between the properties and a foundational part of the object i.e. its body or chassis in the case of a car. The

foundation part is central to the overall representation and is linked to the skeletal image file. The propositional file for a car may contain entries concerning the doors i.e. located to the right and left of the chassis. Each of these parts would have a corresponding image file containing the basic information for constructing the image of a given part of the spatial medium. These propositional files will also contain information such as size category i.e. is it a small car or a large car, and its super-ordinate category i.e. motor vehicle.

Information that is contained in the image and propositional files are connected, therefore detailed parts of the image such as the doors are linked to an image file that contains the co-ordinates for the doors. These co-ordinates will then be used to construct the image of the doors.

When an individual is asked to imagine a car, the propositional and image files are used to produce the image on the spatial medium. Several processes however, can be used to generate the image. These processes can be considered to be commands, the three most important being PICTURE, FIND and PUT. Briefly explained, PICTURE is the process that takes information about the co-ordinate of the image and represents it in the spatial medium with the highest resolution and at a size that fills the region (Eysenck and Keane, 1986). The PUT process directs the PICTURE process by placing the remaining image parts in their correct location on the skeletal image. FIND is used to locate the objects or parts already in the image which the new, to be imaged parts can be related, for example, when the size and location of the doors are known they can be added to the image.

More specific instructions require the commands to SCAN, LOOKFOR, PAN, ZOOM and ROTATE. The ability to SCAN and ROTATE an image is central to Kosslyn's mental scanning studies (Kosslyn, Ball and Reiser, 1978) and Shepard and Metzler's mental rotation studies. Certainly, the ability to scan and rotate is used to explain the results of their studies, which are important to this present study.

2.3.6 Evidence In Favour Of Analogue Coding

As mentioned, Kosslyn, Ball and Reiser (1978) studied the time it takes subjects to scan between two locations on a mental image after having first studied a map and being able to accurately reproduce it. They found that the further apart the two objects the greater the reaction time and that the time taken to scan between objects in the mental image is a function of the distance between objects. This means that greater distances in image space represent larger map distances therefore mental images have spatial properties i.e. spatial distances as opposed to just encoding such properties in some unspecified manner.

This suggests that the subjects were using the same operation for the imaged objects as they would for the physical object. Evidence would suggest that complex or abstract mental images might resort to some sort of verbal labeling whereas simple mental images stored in memory as images are very similar to the actual visual images that the retina receives.

2.3.7. Scanning And Mental Rotation

A study by Shiina, Saito and Suzuki (1997) set out to research which aspect of spatial ability is actually reflected in a participants scores in a Mental Rotations Test. Shiina *et al* compared the performance scores of novice and expert subjects on Shepard-Metzler Tasks (S-M tasks) and took into account individual differences concerning the different types of strategies that were used when solving the tasks.

In the first of their experiments, a cornea reflectance eye tracking system monitored the participants eye fixations while solving the mental rotation task. The tracking system allowed them to record the areas of fixation and the duration of time that subjects spent at each fixation point on the given shape. By doing so, they were able to identify three patterns of eye-fixations.

The experts tended to use simple and systematic mental rotation, using the same fixation pattern, which was termed “r”, in that the subject would repeatedly look back and forth between corresponding segments of each figure. The fixation points traveled from the upper arms of the figure to the lower arms. Once these systematic fixations took place, the subject would respond without the necessity to go through the cycle of fixations again or they would add a short cycle purely for confirmation purposes. This Shiina *et al* termed “r1.5” i.e. one and a half cycles.

The patterns for novices however varied across the participants. Novices tended to solve tasks by using strategies other than purely mental rotation. Their solving strategies were classified by Shiina *et al* as:

1. **Redundant mental rotation:** the participant could not make a judgment after the first cycle of fixations and therefore performed two or more cycles before responding.
2. **Feature detecting together with mental rotations:** After the participant had performed an “r” fixation cycle as described above, they spent a relatively long period of time on one of the figures whereby the locus of fixation moved all over the figure. This was thought to indicate that the participant had looked for structural features i.e. central joint connections or relationships between the upper and lower arms. This pattern was again followed by an “r” fixation cycle.
3. **Matching encoded descriptions:** This pattern indicated that the participant spent lengthy fixation periods with each figure presented with the locus of fixations “tracing” the whole figure. This pattern was then repeated on the second figure in the presentation. Shiina posited that the participant was encoding the actual structure of both figures and then matching the two encoded descriptions.

The strategies they found in the S-M tasks were very similar to those they found in an earlier study by Shiina (1994), where participants were asked to perform Vandenberg’s (1978) Mental Rotation Tasks (MRT). In conclusion, Shiina *et al* (1994) stated that the differences in strategies found in the MRT are not due to the number of alternatives that participants have to choose between before making a response. (In the Shepard and Metzler tests, participants compared a pair of stimuli. In the Vandenburg and Kuse tests, the participants compared the standard shape to a number of possible orientated correct solutions). The differences were

due to individual differences also found in performances in solving S-M tasks where participants were only required to determine whether two figures were the same or different. Further, they concluded that the experts solved S-M tasks by simple and high-speed mental rotation that gave them a high score in the MRT. Novices, however, produced low scores due to slow rotation and the use of redundancy patterns. The wide range of strategies used and lack of unification by the novices was reflected in the number of mistakes that they made and the slowness of their mental rotation. This in turn ultimately affected how many questions they were actually able to solve. Simple and rapid mental rotation by the experts produced high scores in the MRT whilst redundant and slow rotation by the novices produced low scores.

Overall, scores in the MRT reflected both the speed, at which a participant can mentally rotate a three-dimensional figure and their ability to unify a strategy for mental rotation. Their study therefore placed emphasis on whether the participant was a novice or an expert. Although there was no reference to gender differences in their studies, only to individual differences, it is possible that females have a history of poorer performance due to their being novices rather than being female. Practice therefore may culminate in a preferred strategy leading to performances equivalent to that of males. For this present study, such a finding is important for it may indicate that differences in accuracy and timing in MRTs are not due to innate biological sex differences but instead to environmental influences i.e. lack of experience. Why those environmental differences should exist are worthy of exploration as they may in turn be directly influenced by the biological

differences between males and females making the differentiation between nature and nurture virtually impossible.

2.3.8 Pylyshyn's Propositional Theory

The propositional model states that images are stored as sets of propositions. These memory representations are structured according to rules of formation, which have truth-values. Each proposition can either be true or false with respect to the image.

"In this scheme, mental transformations are viewed as operations on the structure of a propositional network that lead to changes in the way the representation is used." (Barfield, Sanford and Foley, J. 1988)

Put simply, propositional coding means that an external stimulus is given an internal representation by means of a verbal description.

Pylyshyn would argue that imagery exists only as a cognitive by-product and of no particular use. As products of perception, images are generated from propositions or statements about the world. These images represent meaningful parts of the world and are generated via meaningful analysis and should not be considered the same as raw unprocessed pictures.

As the storage capacity of the human brain is not finite it is necessary to encode, store and therefore recall only meaningful parts of our environment. The information is stored in terms of propositions or abstract concepts that describe relationships between items. Pylyshyn (1973) argued that the concept of imagery was too vague and that all information, whether visual or verbal, is represented by a single propositional coding model. According to his theory it would not be

impossible to store information in terms of mental images because a huge storage space would be required to store all the images people claim to have.

Propositional theories therefore suggest a process where visual information is transformed into a semantic form. Any incoming visually based information from the environment is converted into propositions as the information is passed from short-term memory (STM) to long-term memory (LTM). When retrieved, the propositions are transformed back into visual information. A proposition is the smallest, single information unit, corresponding generally to an idea. It is useful to consider propositions as simple idea units, rather than as actual words or sentences (Wanner, 1968).

When people report seeing “pictures in their head”, this implies that they are processing the information in their STM. Propositional theorists do not argue against imagery in STM, their arguments are more concerned with the way information is stored in LTM. Retrieving information from LTM in order to produce internal visual images in STM has been described as

“the process of remembering or reasoning about shapes or objects that are not currently before us but must be retrieved from memory or constructed from a description.” (Pinker, 1984, p.3.)

Proponents of pure propositional theory use every day examples to show what they consider to be the inadequacies of Dual Coding Theory. If we store visual information about everyday, familiar objects then it should be easy for us to recall from LTM the direction of the Queen's head on a two pence piece. Propositionists would say that an image of the penny is not stored in memory, only the salient bits of the information. It is these “bits” that are reconstructed as an image. Whether

the Queens head faces right or left is not salient and is therefore generally not remembered, as it was not stored in the first place.

Pylyshyn also criticised Kosslyn, Ball and Reiser, (1978) with regards to “scanning”. They said it takes longer to “see” a feature in a mental image that is further away from where on the image an observer is initially focusing. Pylyshyn asked the question: does the pattern of increasing reaction time arise from a fixed capacity of the image examining system, or could it be altered by changing the participants understanding of the task or the beliefs that they hold about what it would be like to examine, in this case, a real map? Pylyshyn and Bannon, L (1981), repeated scanning experiments but did not ask the participants to imagine scanning the distance between two imagined places. They found that there was no increase in time with increasing distance. Such a result showed that if requested, participants can scan between two places or they can jump from place to place on their imaginary map. This, Pylyshyn explained, showed that the effect of distance on reaction time is cognitively penetrable in other words, reflecting not so much the nature of the mental architecture used in imagery but instead reflects the principle that what observers know, their tacit knowledge, governs the world being imagined.

Similarly, in Pylyshyn’s 1979 study, he showed that when participants were asked to mentally rotate an object, which was supposed to be very heavy, the measured rotation rate was substantially slower than that when the imaged object was supposed to be very light. This argues against the conclusion that mental rotation is a fundamental, architectural property of the mind. Object complexity also

showed significant effects (Yuille and Steiger, 1982 and Barfield, 1986). Such findings cast doubt on the analogue theory of mental rotation.

Propositional representations are therefore explicit, discrete, abstract entities that represent the ideational content of the mind (Eysenck and Keane 1986) and are not specific to any modality i.e. touch, olfaction or vision. They represent conceptual objects and relations in a form that is not specific to a language, as we would understand it, more a universal mentalese. It is in this mentalese or code that all cognitive activities are carried out by using a logical system called *predicate calculus*.

2.3.9 Predicate Calculus

The predicate calculus provides a way for relating together object like entities that form the content of the mind. These relations are represented as *predicates* and the object entities are *arguments* of the predicates. To be more precise, if the idea “the book is on the table”, is to be expressed, the relationship between book and table is the predicate ON. (that is the mental content of ON and not the word “on”). The predicate ON therefore links together the arguments the BOOK and the TABLE, expressed ON (BOOK, TABLE) to show that ON takes the two arguments.

Predicates can take any number of arguments. A simple sentence such as “Colin cut Peter with the knife and the knife was sharp” could be written:

CUT (COLIN, PETER, KNIFE)

SHARP (KNIFE)

It can be seen that the predicates CUT and SHARP are first order predicates whereby they take object constants as their arguments. When a predicate and a number of arguments are combined in this way, the whole form is called a proposition. However, there are also second-order predicates that take propositions as their arguments, for example the second order predicate CAUSE can link two propositions. Consider the following example: “Colin cut Peter with the knife and he was crying”. This could be written as:

CAUSE[CUT(COLIN, PETER, KNIFE),
 CRYING(COLIN, PETER)

These notations have been used by cognitive psychologists to express mental, propositional representations, in order to show that ideational content can be stated in terms of predicates taking one or more arguments.

The debate concerning imagery therefore concerns two basic questions. The first concerns whether or not imagery is different from propositional representation. Kosslyn would argue that images are picture like and operate in their own medium. Pylyshyn would argue that images are really propositional representations.

The second question that arises is whether imagery has any functional significance. The term *epiphenomenon* is used to describe something that has no causal significance to some event. It might be argued that imagery occurs in the mind but it has no causal significance to cognition. Put simply, if we could not

see “pictures in our heads” we would still be able to think and problem-solve, cognition would continue operating.

2.3.10. Pylyshyn on Mental Rotation.

Pylyshyn did not question the rotation of the figures in Shepard and Metzler’s test nor did he question the participants description of how they carry out the task i.e. by mentally rotating the shapes. His question related to whether or not we actually do mentally rotate the figure, which is quite different from thinking or imagining that that is what we do. Pylyshyn stated that if it were the case that during the actual mental rotation, the figure moved as a rigid form through a range of orientations, then the mental rotation would be using an intrinsic property of the image format. He argued, however, that figural rotation is not a holistic process operating on the whole figure thereby ensuring that the figure retains its rigid shape. Instead, Pylyshyn (1979) argued that the apparent rate of rotation, as suggested by Shepard and Metzler, depended on the complexity of the figure. He suggested that the dependence of the rotation speed on such organisational and task factors showed that something other than the rotation of a figure in a rigid manner was occurring in order to make its orientation align with that of the reference figure.

To explain, Pylyshyn argued that even if the comparison process actually did involve rotation, this in itself says little about how the form of the figure is represented and does not support the view that the representation is pictorial, as Shepard would argue.

It cannot literally be true, Pylyshyn stated

“ that a representation maintains its shape because of the inherent rigidity of the image while it is rotated... The representation is not literally being rotated; no codes or patterns of codes are being moved in a circular motion.” (P16)

He believes that at most a representation of a figure is processed in such a way as to produce a representation of a figure at a slightly different orientation and then this process is repeated perhaps continuously. In the Shepard and Metzler tests, comparison time may well have increased with the angular disparity between figures because of some computational resource considerations such as repeating parts of a form over successive small angles and general architectural constraints such as working memory and therefore applies regardless of the form of the representation. Indeed, studies by Hochberg and Gellman (1977) found participants tended to concentrate on significant features of the figure when carrying out comparison tasks. If such features are available then no rotation effect is found.

Pylyshyn concluded that the Shepard and Metzler rotation results did not offer any proof of the format of image representations or even the form of their representations and warned that treating the phenomenology as explanatory does not help the understanding of how or why behavior occurs.

2.3.11 The Hybrid Theory.

Research by Barfield, Sandford and Foley, (1988) into mental rotation and the perceived realism of computer-generated three-dimensional images, tested several models that describe the internal representation of graphic images in memory. They tested complexity by manipulating the placement and number of right-angle

bends in the construction of the image, and by the type of image (wire-frame or shaded). Their results for reaction time showed strong effects for object complexity across angles of rotation and also for light sources across angles of rotation. However, they concluded that their study did not fully support either an analogue or a propositional view for mental rotation performance but that a hybrid model may be more to their advantage.

They gave, as an example of explanation their finding that a significant two-way interaction between object complexity and angle of rotation supports a propositional account for mental rotation. Also, the non-significant relationship between shading and angle of rotation supports the analogue model. Barfield *et al* gave a possible explanation for their results by focusing on the process in which propositions are formed on the stimuli objects. They suggested that objects differing in basic form required different sets of propositions to describe their forms. This difference would affect the rate at which propositions are manipulated during the rotation process. In their study, the flat and smooth shaded images were of the same basic form and the propositional descriptions were either the same or very similar and produced data supporting the analogue model. To conclude, they believed that their results implied that characteristics of the task and stimulus affect the mode of processing for mental rotation tasks.

Research carried out by Bryden *et al* (1987) into complexity effects found that none of their manipulations affected the rate of mental rotation. Barfield *et al* compared Bryden's results with that of Yuille and Steiger (1987) and their own stimuli images. Barfield's were less complex forms, in that both Bryden and

Yuille and Steiger used similar basic forms to Barfield's but with additional complexity manipulations. Both sets of researchers added several protrusions to their objects located at right angles off the main axes of the object. Bryden *et al* did not find a significant relationship between mental rotation rates and object complexity and found no significant difference in response time for wire-frame versus shaded objects. Barfield *et al* suggest that Bryden's images may not have approached a level of complexity sufficient such that propositional networks in long-term memory needed to be addressed. The same could therefore be said for Shepard and Metzler's original findings in that their stimuli were far too simple to need to tap into propositional networks and that the analogue model was sufficient for their findings.

Barfield, Salvendy and Foley (1987) developed a hybrid model containing both analogue and propositional features. To be taken into consideration when performing mental rotation tasks are the capabilities of human short-term and long-term memory as must be the characteristics of the task. It is also important to include the integral and non-integral properties of the stimulus. According to Barfield *et al*, analogue processing occurs for tasks that do not need to draw upon information stored in long-term memory as they are below some level of complexity. Although not stating what that level is, they suggest that integral stimuli lead to analogue or parallel processing, whereas non-integral stimuli lead to propositional or serial processing.

Shepard (1964) classified integral stimuli as those that are related as homogeneous, unitary wholes. Barfield gives the example of colour as it can vary

in hue, brightness and saturation. Lockhead (1972) noted that integral stimuli, consists of multiple stimulus dimensions on which the observer can operate simultaneously. Lockhead in fact argues for a holistic perception of integral stimuli whose components cannot be processed independently. It has to be noted that there are critics of Lockhead's argument (Massaro, 1995)

2.4. The Advantages Of Imagery And Mental Rotation

So what is the advantage of imaging or “seeing with the minds eye”? Practical applications range from simple tasks such as solving jigsaw puzzles to the complex, such as the ability to read sign language. Deaf signers are understood from the signers perspective Bellugi and Klima, (1978). In order to understand the message sent by the deaf signer, the receiver has to mentally rotate the sign productions (mirror images).

Imaging is a cognitive skill involved in the process of designing allowing the ability to create internal models and enabling us to plan how things might be and to speculate about the future. Mental rotation of an image or an object is part of the process of visualisation and is therefore necessary in designing. Being able to visualise problems is critical, for example, engineering students; especially those embarking on computer aided design courses. However, such spatial skills are critical in many other fields of study and researchers have identified over 86 different careers where spatial visualisation skills are essential for success ((Sorby and Baartmans, 1996)

Also, part of the requirement for the Air Force ROTC program is the Air Force Officers Qualifying Test whereby participants are shown photographs of airplanes

at various orientations and they are to predict the maneuvers needed to intercept or avoid another plane. Further photographs show aerial pictures from which the participant has to predict the maneuvers needed to bring a plane over a target from a particular direction. The Pilots Spatial Test (PST) is a procedure for assessing navigation skills and orientation in space which has high power in the upper range of performance in ability and aptitude testing, in traffic psychology, specifically aeronautics and space travel, and in industrial medicine. This test also involves showing participants two images of aeroplanes in different positions and to decide how this change in position (rotation about 3 spatial axes) was brought about. The participants are presented with pairs of pictures supplying altitude information as commonly used in contact flight or instrument flight. Bodner advised that the change in the direction in which a plane flies could be thought of in terms of three modes of motion – pitch, yaw and roll.

These modes of motion require the same thought processes as the tasks encountered in chemistry courses where students are asked, for example, to envision what happens when rotating a mental image of a molecule. Research therefore, has found that spatial ability can be linked directly to a students performance in chemistry courses (Bodner and Guay (1997). Their study used a battery of spatial tests, including the Purdue Visualization of Rotations test (ROT) that was used in this present study. Their findings showed a highly significant correlation between spatial ability and spatially oriented tasks in general chemistry and between students' scores on spatial ability tests and their performance on questions such as:

- Calculate the fraction of empty space in a face-centred cubic unit cell.

- Titanium metal crystallizes in a body-centred cubic unit cell. The distance between nearest titanium atoms is: (a) a (b) $\frac{1}{2}a$ (c) $\frac{2}{3}a$ (d) $\frac{3}{2}a$ (e) none of these.

The conclusions were that the correlation between spatial ability and problem solving performance results show the relative importance of *preliminary stages* of problem solving in determining whether a student is successful on tasks they encounter in their introductory courses. These are stages in which relevant information must be disembedded from the statement of the problem and then *transformed* or restructured until the individual begins to understand the problem.

Bodner stated that it is at these preliminary stages that the first steps are taken towards building a mental representation of the problem. Bodner has written extensively on the processes by which students use algorithms or very simple problem solving strategies to work routine exercises and the more complex process they use when faced with questions that are *novel* problems (Bodner, 1987, Bodner, 1991). This may reflect the difference between using analogue or propositional strategies. Propositional models may be used for novel and initially complex problems and analogue for familiar and simple problems.

2.5 Sex/Gender

Of importance to this present study is the fact that mental rotation tests consistently show a robust gender difference, favouring males. Vandenburg and Kuse (1978) constructed a paper and pencil test of spatial visualisation from the figures used in the Shepard and Metzler (1971) study. Their test consisted of five

sets of four items. Each item consisted of a criterion figure, two correct alternatives and two incorrect or distractors. The participant was to choose which of the figures matched the criterion figure. They found consistent gender differences favouring males, over the entire range of ages investigated, adding that participants reported that the MRT, in comparison to other spatial tests, was more difficult to solve verbally. Vandenburg and Kuse suggested that this may explain why the gender difference in favour of males, was so pronounced. Other researchers have also found such gender differences favouring males. (Defries, Ashton, Johnson, Kuse, Mclearn, Rashad, Vandenburg and Wilson. 1976).

Put simply, research suggests that, on average, the female brain performs better on some skills while the male brain executes other tasks at a higher level. (See chapter four for a fuller discussion) For example, tests show that females generally recall lists of words or paragraphs of text more successfully than men do. On the other hand, males usually perform better on tests that require the ability to mentally rotate an image in order to solve a problem. Females tend to be more intuitive and better equipped to notice things which males are generally oblivious to. However, males have an apparent greater spatial ability in that they can picture things, their shape, position, geography and proportion with greater accuracy in their “minds eye”. Women have greater language skills and perform better than males on tests of verbal ability. Mathematically, males outperform women in their ability to resolve abstract concepts of space relations and theory.

Bodner and Guay (1997) also found gender differences on spatial performance with regards to their ROT test. They found that the males outperformed females

and that the difference was not only large but also statistically significant. They stated that about three-quarters of males scored at or above the female mean and that in all but one of the studies the difference between the male and female means was larger than two-thirds of the standard deviation of the scores.

Barfield, Sandford and Foley (1988) also noted gender differences in that they reported consistent differences between males and females on rates of mental rotation in favour of males. They also noted that, in general, females made more errors for “same different” responses than did males, which they felt reflected a more variable mix of strategies among females. They proposed that there are four stages involved in mental rotation tasks.

1. Encoding of the target and stimulus.
2. Some form of either object rotation or propositional rotation process
3. Comparison of the two images
4. A “ same” or “different” response.

They suggested that, from their own error data, image comparison strategies might also account for the gender differences. Females are known to be more successful at multi-tasking and this may reflect the strategy they choose for problem solving. The propositional model is more complex than the analogue model therefore requiring more cognitive resources and more suitable for focused problem solving than multi-tasking.

Although, performance on mental rotation tests have consistently shown robust cognitive gender differences, favouring males, many researchers would argue that these differences have diminished in recent decades (Caplan, MacPherson and

Tobin 1985, MacIntyre, 1997). Voyer, Voyer and Bryden (1995) have also shown evidence that the spatial differences between the sexes are diminishing, except for the mental rotation test. Why these differences might be are discussed in chapter four.

2.6 Mental Rotation Studied by Functional Magnetic Resonance Imaging.

As mental imagery is an important cognitive problem solving skill and the mental rotation of complex objects is the most extensively studied mental imagery task, fMRI has recently been used to observe focal changes in blood flow whilst subjects took part in performing mental rotation tasks. A study by Cohen et al (2000), using objects from the original Shepard and Metzler study, found that there data was consistent with the hypothesis that mental rotation engages cortical areas involved in tracking moving objects and encoding spatial relations. There was also little evidence for lateralisation of the cortical activity or of engagement of the motor cortex. Concerning laterality of activation, Cohen states that areas of activation, determined by the presence of suprathreshold signal change in anatomically identified regions, were overwhelmingly bilateral. As a whole, more activity was seen on the Left hemisphere than on the Right.

They cite prior blood flow studies with Xenon-133 (Deutsch, Bourbon, Papanicolaou and Eisenberg, 1988) that suggested greater activation on the right hemisphere than on the left in this task. However, Cohen stated that methodological limitations prohibited quantitative estimates of the laterality and goes on to cite Tagaris *et al* (1994) who, also using fMRI, found greater activation in the left hemisphere. Interestingly, Cohen also adds that their data suggests that visual motion centers, particularly areas MT/V5 ordinarily active in the

processing of motion information, may be involved in mental rotation. This area may be engaged in calculating the pseudo motions needed to bring two two-dimensional representations of a three-dimensional object into congruence. Although there data is limited, if correct, it suggests that the visual motion centers are involved in solving spatial problems using two-dimensional figures and as such gives support to Shepard's observation that mental rotation appears behaviourally like constant velocity object rotation.

Although Cohen *et al* admit that there data are not definitive, however, they feel confident that they can speculate that mental rotation problems may be solved by forming mental images of the rotation of individual elements of the object. These elements are then rotated within cortical areas specialised for the detection of motion. These rotated elements may be matched, in the superior parietal lobule, which is thought to perform transformations of visual space, against templates stored there or somewhere else. In conclusion Cohen wrote:

"Our data are wholly consistent with the theory that mental imagery problems are handled neurally by engaging cortical areas that might otherwise be used in the processing of directly presented stimuli." (Pg. 6)

2.6.1 Problems With Lateralisation Tests.

As mental rotation is, by and large, a spatial ability, it could be assumed that it would be a task performed by the right hemisphere (Linn & Petersen, 1985). Indeed, there are many studies that report such right hemisphere superiority when performing mental rotation tasks (Corballis & Sergent, 1988, Deutsch, Bourbon, Papanicolaou and Eisenberg, 1988). There are, however, studies that have found left hemisphere superiority (Hatta, 1978, Fischer and Pelligrino 1988), as there are

studies that show no hemisphere advantage for mental rotation (Corballis, Macadie and Beale.1985)

Some of the inconsistencies found in studies of the lateralisation of mental rotation may be due to the general level of spatial ability that individual subjects possess. These individual differences may not have been controlled for. A study by Voyer and Bryden (1990), using a lateralised two-dimensional mental rotation task, found not only the usual result that the angle of rotation and reaction time are linearly related, but also that there was a significant spatial ability by visual field interaction.

Their study looked at the relationship between spatial ability and the lateralisation of mental rotation. Using findings from previous research by Bowers and LaBarba (1988), Voyer proposed that participants with high spatial abilities would show a right visual field advantage (left hemisphere) when performing a lateralised mental rotation task and those with low spatial ability would show a left visual field advantage (right hemisphere). Interestingly, he found his hypothesis to be correct except that the gender of his participants also interacted with visual field. Males showed left visual field superiority (right hemisphere) and females showed a right visual field vantage (left hemisphere), although not significantly so. His results suggest that males have a greater tendency to use right hemispheric processes to perform two-dimensional mental rotation tasks whereas females are more bilaterally represented.

Further, his results showed a significant three-way interaction of gender, spatial ability and angle of rotation. The results of his study not only showed that low spatial males were profoundly affected by rotation but also that females were generally faster than males on the task. This result is contrary to the findings, which generally favour males in spatial tasks. He surmised that some of the inconsistent findings in lateralisation studies of mental rotation might be due to differences in spatial ability.

The effect of practice was also considered in Voyer's study as he found that the different patterns of visual field asymmetries found in participants with increasing levels of spatial ability provided support for the hypothesis that the right hemisphere has a greater ability to process novel stimuli, while the left hemisphere is superior at utilizing familiar stimuli. A participant with low spatial ability will probably have no or little experience with mental rotation, therefore the right hemispheres specialisation in processing novel or complex stimuli would come into play explaining why low spatial ability subjects show a left field advantage. In contrast those participants who have high spatial abilities were presumably familiar with tasks that involve mental rotation and consequently the left hemisphere, with its superiority at processing familiar stimuli, is favoured.

Voyer and Bryden go on to explain that their results concerning gender by visual field interaction suggested that males are more likely to use right hemisphere processes to perform two-dimensional mental rotation, whereas females rely on bilaterally represented processes to perform the same task. Their finding, that there is an interaction between spatial ability and visual fields, is explained by the

fact that the differing patterns of visual field asymmetries found in participants with increasing levels of spatial ability supports the hypothesis that the right hemisphere has a greater ability to process novel stimuli while the left hemisphere is superior at using familiar stimuli.

These results reflect Bodner's (1987) findings concerning student performance, stated earlier, that students use algorithms or very simple problem solving strategies to work routine exercises and the more complex process they use when faced with questions that are novel problems. These findings imply that when subjects initially have a left visual field advantage because the task is novel to them, practice and familiarisation with the task and stimuli will eventually lead to a right field advantage shift.

Research by Hatta (1978) indicated some of the problems associated with brain laterality studies in that different experimental tasks require different individual higher psychological processes. For instance, some tasks may require visual or holistic coding processes that are linked to the right hemisphere or they may require verbal or serial processing which are linked to the left hemisphere. However, Hatta maintained that it is the left hemisphere that is superior for higher-order cognitive tasks such as mental rotation and categorisation. The right hemisphere is superior for lower psychological processes such as perception and discrimination. This supports Voyer *et al's* finding that their participants with high spatial ability showed a left hemisphere advantage (familiar) while subjects with a low spatial ability showed a right hemisphere advantage (novel)

2.6.2 Eliminating Gender Differences: Practice

The Naval Air Warfare Center Training Systems Division has been keen to find ways of eradicating any gender differences in spatial ability. Research conducted by Kass and Ahlers, (1998) recognised how crucial mental rotation ability are to many real world tasks. With reference to the Navy, their concern lay with the scenario that onboard a submarine, certain crewmembers have to look through a periscope to provide an estimate of a surface ships orientation. This, they explain, requires the viewer to use their perceptual judgement to estimate how many degrees the visual contact is rotated from 0 degrees (i.e., bow of the ship pointed directly toward the view). This measure is known as “angle on the bow” or AOB and in order to maintain the submarines advantage, this visual spatial task must be carried out quickly and accurately.

Consistent with Shepard and Metzler’s findings, Kass and Ahlers reported that the further the image of a ship had to be mentally rotated to estimate the angle on the bow, the longer the time taken to respond. With females playing a greater role in the armed forces and reaching the higher ranks, the Naval establishments are researching the apparent gender differences that emerge in spatial ability tasks such as estimating accurately the angle of the bow. Working with the hypothesis that gender differences in mental rotation are due to experience i.e. environmental factors rather than hormonal, genetic etc., then good training is all that is needed for females to perform as well as men on a “stereotypically male, applied, spatial task”, such as calculating angle on the bow.

Their research did indeed find a gender difference, in favour of males, for AOB estimations. However, they found that only half an hour of practice with feedback reduced the performance difference to a negligible status. In the practice with feedback condition, participants were given an initial definition of AOB and were also allowed to view a simulated perspective view through the lens of a periscope positioned 3 feet above the surface of the water. Via this simulation, they saw three 3-Dimensional surface ship models in the head on position. The participants were given 78 trials in which the ships model appeared on screen for a short duration after which they had to estimate the ships AOB. The ship models were shown at all 15 degree angle increments from 0 to 180 degrees. Feedback consisted of supplying the participant with their estimated AOB and with the actual AOB after each trial. This form of feedback meant that the participant was able to reduce the difference between their estimates of AOB and the actual rotation of the stimulus.

The 78 practice trials afforded the participants the opportunity to “*develop more referant mental images of the stimuli*” (pg. 346) as each of the three ships models were viewed in 13 different orientations. Kass and Ahlers suggested that the participant might match the test stimulus to the closest referant image and mentally rotate either the referant or the test stimulus to determine the angle discrepancy. The more referant images available to the participant the less amount of rotation is required. This then is a compromise between Pylyshyn’s propositional representation and Shepard and Metzler’s mental rotation theory in that the participants may have relied on stored knowledge of the stimulus as well as mentally rotating the stimulus when calculating its angle on the bow. They

refer to Kail and Park's (1990) observation that mental rotation practice leads to an increase in the number and strength of stimulus representations that can be retrieved directly from memory.

Kass and Ahlers naval experiment also highlighted that the men who undertook no training performed as well as the men who were trained. This suggested that due to their extensive practice with various spatial tasks throughout their life span, males were already equipped with the necessary spatial skills to perform the mental rotation task and that further training was of no real benefit to them. However, it only took the females half an hour of practice to perform as equally well as their male colleagues. Their findings showed that the men in all their training conditions performed equally well, suggesting the possibility of a ceiling effect. Women in the performance feedback group also performed equally as well as the males suggesting that they too had reached the performance ceiling.

It is possible that life's experiences had meant that the males had already reached their fullest potential even before practice was undertaken, the women however, having no, or very little spatial experience, took only a small amount of practice to reach the same performance level as the men. This finding is supported by Law, Pellegrino and Hunt (1993) who suggested that through practice with feedback male and female performance on spatial tasks would converge at asymptote.

In Tarr and Pinker's (1989) study of mental rotation and orientation-dependence in shape recognition, participants were asked to study objects presented at a single orientation. They were then given extensive practice at naming the objects quickly

or deciding if the objects were normal or mirror reversed, at several orientations. At first the results were similar to those found by Shepard and Metzler suggesting that the participants made judgments by mentally transforming the orientation of the input shape to the one they had just been presented with.

With practice, participants recognised the objects almost equally quickly at all familiar orientations. Participants were then probed with the same object but at novel orientations. Tarr and Pinker found that *“the response times for these probes increased with increasing disparity from the previously trained orientations”*(pg.233). They suggested that participants had stored representations of the shapes at each of the practice orientations and recognised shapes at the new orientations by rotating them to one of the stored orientations. Such findings can be further explained by Voyer and Bryden’s (1995) explanation that the right hemisphere has a greater ability to process novel stimuli while the left hemisphere is superior at using familiar stimuli.

Tarr and Pinker went on to say that when mirror images of trained shapes were presented for naming, participants took the same time at all orientations. This, they claim, suggested that mental transformations of orientation can take the shortest path of rotation that will align an input shape and its memorised counterpart, in this case a rotation in depth about an axis in the picture plane.

It is important to understand that novel does not necessarily imply complex nor does familiar imply simple. A novel stimulus is simply an object or problem to be solved, whether complex or simple, that the participant has not come across

before and therefore has no set strategy to deal with it. A familiar stimulus, whether complex or simple, implies that the participant has come across this object/problem before or something similar and already has a strategy formulated. The more often the strategy has been used successfully the quicker the participant will be at applying it.

Practice will be viewed as a factor effecting performance in this present study. In phase two of the experiments in this present study, the participants will be tested on a mental rotation test over a period of time to see if practice will diminish differences in performance.

2.6.3 Stereotyping/self-perception:

The results obtained by Kass and Ahlers (1998) support the environmental argument that the gender differences in spatial ability are primarily due to lack of experience on behalf of the females. Sharp, Price, and Williams (1994) support the view that it is socio-cultural expectations of male and female roles and what is considered to be a masculine or feminine task that effects spatial task performance. The very fact that there are very few women onboard submarines indicated that the task performed by Kass and Ahlers participants was stereotypically masculine and probably perceived as such by the females. This may also go some way towards accounting for the gender differences found by Bodner both in the Air Force Officers Qualifying Test and his first year chemistry students who undertook the Purdue Visualization of Rotations test. It is conceivable that chemistry and flying are still perceived as being primarily male domains and that self perception or stereotyping may well have a greater effect on results than gender per se.

The effects of such stereotyping can be seen in the study conducted by Shih and Ambady (1999). The investigators used positive and negative stereotyping to manipulate the performance of Asian American women who completed a maths test. They found that in the positive stereotype condition where the women were identified with the stereotype that Asian people excel at quantitative skills, thereby evoking an identity, associated with a positive performance. The negative stereotype was that women are poorer at quantitative skills than men. The results showed that the positive group performed significantly better than did the negative group. Self- perception and the effect of stereotyping will be investigated in this present study as an important factor effecting performance. A comprehensive overview of the effects of such factors will be covered in chapter four. Phase two experiments will manipulate the way in which participants view themselves and their potential performance in a mental rotation test.

2.7 Summary.

Spatial cognition is a mental process associated with attempts to interpret incoming visual information such as pictures, maps and plans. Without the ability to comprehend and interpret visual information an action as simple as remembering how to navigate from the living room to the front door would be impossible. Mental rotation is an important component of spatial cognition in that everyday life events from parking the car to reading a map require this imaginal visio-spatial transformation ability.

Despite centuries of introspective thought and decades of research, the debate still goes on to explain just how we picture objects or events in our heads. Do we use analogue or propositional processes or a hybrid of the two? Whatever the

answer, it is evident from the literature that males consistently outperform females on mental rotation tests. On a purely practical basis this is a concern as the ability to imagine and mentally rotate objects are cognitive skills involved in anything from learning sign language to engineering, jigsaw puzzles to mathematics and chemistry to planning for the future.

Briefly, the effect of prior experience and self-perception has been touched on and in some studies the eradication of gender differences in MRTs have been achieved. This will be looked at in detail in the experimental chapters. Why there are differences in cognitive abilities, in this case mental rotation, will be discussed in chapter four as it will be important for this present study to be able to distinguish between sex differences, which cannot be altered (other than through surgical or hormonal means) and environmental differences which can be altered through learning and experience.

Chapter Three

Encoding and Navigating the Environment.

In order to address the questions that arose in chapter one it will first be necessary to understand how human beings are able to negotiate the world, to understand how we can encode and navigate the environment in which we live. The first topic to be covered will be how we perceive space in natural environments because without a firm grounding in the basics of visual perception it will not be possible to understand how we perceive depth and how this information helps us to navigate real and virtual environments and any problems that may arise. The issue of sensory conflict will also be discussed as motion or cyber-sickness, is often experienced by users of VR and, as mentioned in chapter 1.1.6, Parker and Harm (1992) believe that poor mental rotation ability may be the root cause. Navigational awareness, defined as having a complete navigational knowledge of an environment (Satalich, 2000) will be discussed in detail as the difference in navigational strategies, whether developing landmark or survey knowledge, is fundamental to the differences in the way males and females navigate their environments.

Further consideration will be given to cognitive maps made while navigating a virtual environment as studies have shown that the construction of cognitive maps built during navigation of a VE is comparable to those constructed in a real environment (Witmer, Bailey and Knerr, 1996). This is an important issue to cover, as training using a VE can only be successful if the knowledge or skills gained whilst in the virtual world can be transferred and applied to the real world.

(Waller, Hunt and Knapp 1998). The final sections are crucial to the understanding of differences in performance between males and females by first looking at evidence produced by neuroscience in establishing the areas of the brain that are used in navigation and any sex differences that occur. Finally an evolutionary perspective will be given to explain the possible development of sex differences, one of them being the Hunter-Gatherer Theory (Eals and Silverman, 1994) that is based on the idea that selection for spatial dimorphism in humans was due to the sexual division of labour. This chapter will therefore provide a thorough understanding of how human beings are able to navigate their environment whether it is real or virtual.

3.1 Perceiving Space In Natural Environments

Perception is the process of organising, interpreting, and selectively extracting sensory information. However, vision is our most dominant sense and most of our information about the world is derived from light that enters the eyes. The brain, allowing us to be part of and navigate through, a three-dimension environment then processes this information.

To navigate in a three-dimensional world, it is vital that we are able to recognise objects and to judge distances in depth. The brain allows us to reconstruct three-dimensional images from the two-dimensional pattern of light that falls on our eyes in two ways, from differences between the two eyes (stereopsis) and from monocular cues. We can perceive depth in a flat object, such as a photograph because this process happens at a fairly low level of the visual system, and is

therefore subjectively powerful; it is very difficult to perceive a line drawing as simply a flat collection of lines.

Retinal disparity occurs when our eyes converge on an object (see Fig. 3.1) but its image falls on different points of the two retinas, the amount of difference or disparity between the two retinal images can be used as a cue to distance. However, when we fixate distant objects, the separation of the eyes is not sufficient to produce any disparity between the two eyes. Above a certain distance, which is approximately one hundred feet for human eyes, we use monocular cues. There are several cues, which are used to judge the relative distance of objects.

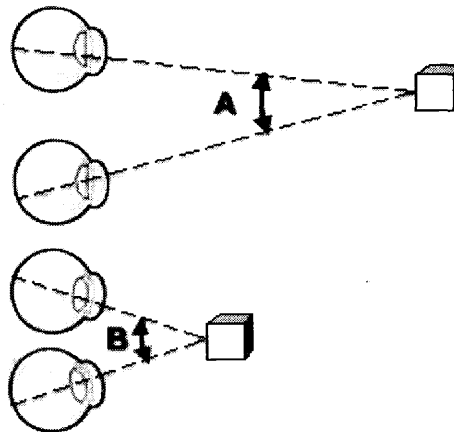


Fig. 3.1. Convergence, the angle made by the two viewing axes of a pair of eyes

3.2 Monocular Cues:

Monocular cues are of particular importance when looking at a two-dimensional image such as a photograph as they create a powerful impression of depth. People however, perceive space and understand the layout or depth of a cluttered natural environment by using some or all sources of information such as occlusion, height in the visual field, relative size, relative density, aerial perspective, binocular disparities, accommodation, convergence, and motion perspective (Cutting 1997).

Occlusion- when one object hides or partly hides another from view.

Height in visual field - measures relations among the bases of objects in a 3-D environment as projected to the eye, moving from the bottom of the visual field to the top, and assuming the presence of a ground plane, of gravity, and the absence of a ceiling. This therefore refers to – relative height, elevation or height in the visual field and serves as a spatial cue when viewing two-dimensional pictures because objects that appear below the horizon tend to appear closer than those above the horizon.

Relative size - a measure of the angular extent of the retinal projection of two or more similar objects or textures.

Relative density - the projected number of similar objects or textures per solid visual angle.

Aerial perspective - the increasing indistinctness of objects with distance, determined by moisture and/or pollutants in the atmosphere between the observer and these objects.

Binocular disparities - the difference in relative position of an object as projected on the retinas of the two eyes.

Accommodation - the change in the shape of the lens of the eye, allowing it to focus on objects near or far while keeping the retinal image sharp.

Convergence - the angle between foveal axes of the two eyes.

Motion perspective - the field of relative motion of objects rigidly attached to a ground plane around a moving observer (Helmholz 1867). This does not refer to object motion.

The filmmaker Emmanuelle Toulet first used motion perspective at the turn of the 19th century. Toulet would mount a camera on the front of a train or car and the resulting film created for the audience the illusion of motion, often quite spectacularly.

Cutting, (1997) did not include texture gradient, linear perspective, brightness and shading, kinetic depth, kinetic occlusion and disocclusion and gravity amongst his main sources of information about depth.

3.3 Space Around A Moving Observer

Cutting studied the usefulness of the aforementioned sources at different distances and found that there are three classes of space around a moving observer:

Personal space - this is limited to about 1.5 meters from a typically stationary, individuals head. Cutting found that within this space there are five important sources of depth information. In order of relative importance and making the assumption that they are available, they are: occlusion, retinal disparity, relative size, convergence and accommodation.

Action space - is defined as a circular, generally planar region beyond personal space. Cutting advises that we move quickly, talk or even throw things within this space. The order of sources in this space is: occlusion, height in the visual field, binocular disparity, motion perspective, and relative size. The limits of action space are defined at about 30 meters from the observer because past that point, the utility of binocular disparity and motion perspective decline to 10%, effectively delimiting the action space at its furthest boundary.

Vista space – is defined by Cutting as being the space that occurs beyond 30 meters, extending to the limits of sight. The effectiveness of binocular disparity and motion perspective is negligible at this distance, therefore occlusion, height in the visual field, relative size, relative density, and aerial perspective are defined as the most important cues in this space.

3.4 Linear Perspective.

Linear perspective is important to this present research as transparent “wire-frame” mental rotation tests were administered to participants. Being transparent means that the “wire-frame” of the shapes gave the added advantage of perspective that was not as evident in the original Shepard and Metzler (1971). Using perspective to help solve 3D mental rotation tests may give an indication to how performance within a VE can be improved, particularly with regards to individuals with poor spatial ability. Linear perspective will therefore be discussed in greater detail than other depth cues in order to develop a deeper understanding of its contribution to depth perception.

Linear perspective is a depth cue that is related to both relative size and texture gradient. In linear perspective, parallel lines that recede into the distance appear to get closer together or converge. Converging lines are perceived as showing depth even in a simple line drawing because the visual system tends to interpret converging lines as remaining parallel in depth. A greater degree of convergence leads to a greater impression of depth. Because of the similarity of how this depth cue works, Cutting has argued that it is not a separate cue from relative size and texture gradient. The use of linear perspective can be seen clearly in a painting of a street scene by Gustave Caillebote (see fig.3.2).



Fig. 3.2 Paris Street: Rainy Day by Gustave Caillebote showing the use of linear perspective to create the impression of depth.

<http://psych.hanover.edu/krantz/art/index.page.html>

By looking at the buildings in the background of the painting, *Paris Street: A Rainy Day* by Gustave Caillebote, the separation between the floors is clearly indicated. These lines converge and give the impression that the building is angled and that the surfaces recede in depth. Parallel lines, therefore, indicate a flat surface and converging lines that we see as parallel, indicate a surface that recedes in depth.

3.4.1 How We Perceive Perspective.

We try to impose meaning on what we see in the world by seeking to turn images into objects wherever possible. One such imposition is that of depth which can be interpreted as trying to make shapes more like tangible 3D objects. If an image lends itself to a possible interpretation in 3D we seem to prefer this interpretation. An image of its kind is shown in Fig.3.3. The figures appear to get larger as they near the top right-hand corner, however, from previous experience with such images, we know that the three figures are in fact all the same size. As humans, we find it difficult to avoid interpreting the converging lines as indicating linear perspective. This means accepting that the figure is breaking the rules by appearing to be larger rather than smaller as it gets further away. The desire to interpret in depth is very strong as we, in the West, are familiar with linear perspective.

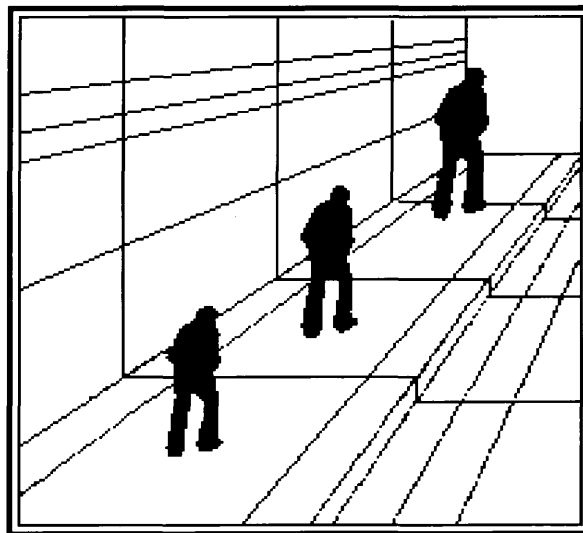


Fig.3.3. The figure in this picture appears to get larger as it nears the top right corner as we interpret the converging lines as indicating linear perspective.

3.4.2. Interpretation of perspective: Nature or nurture?

Optical illusions are one way of illustrating how our brain tries to make sense of incoming data. Processing of visual information occurs at all stages along the visual pathway from the retina to the brain. In the case of illusions, the brain tries to actively process ambiguous information and make some kind of sense out of it, often in vain. Therefore there is a distinction between *sensation*, which is the act of receiving raw data and *perception*, which is the active processing of making sense of what is being perceived. There are two aspects to this data processing:

Bottom up processes are data driven and envisage visual processing as beginning at the lower level of sensory receptors and working upwards to higher levels of perception analysis.

Top down processes see perception as an interpretative process, with perception being concept driven, specific knowledge about the world is thought to be necessary for interpretation of what is seen, for example from learning, past experience and expectations.

In the case of visual illusions, it is argued that our cultural experiences play an important role. How we interpret illusions is connected with our conventional portrayals of perspective in the two-dimensions of paper and canvas and the world we live in and in the case of Western societies, we live in a “carpentered world” that is full of rectangular objects. Gregory (1966) argued that societies that do not share our perceptual experiences of the world do not share our experiences of visual illusions in that they do not have the same effect. Gregory gave the example of Zulus as being a people who live in a non-perspective world or

“circular culture”. They live in round huts with circular corrals, plough the land in curves and have few possessions that have corners or straight lines. It was found that the Muller-Lyer arrow illusion was experienced only to a small extent and that they were hardly affected by other distortion illusion figures (see Fig 3.4)

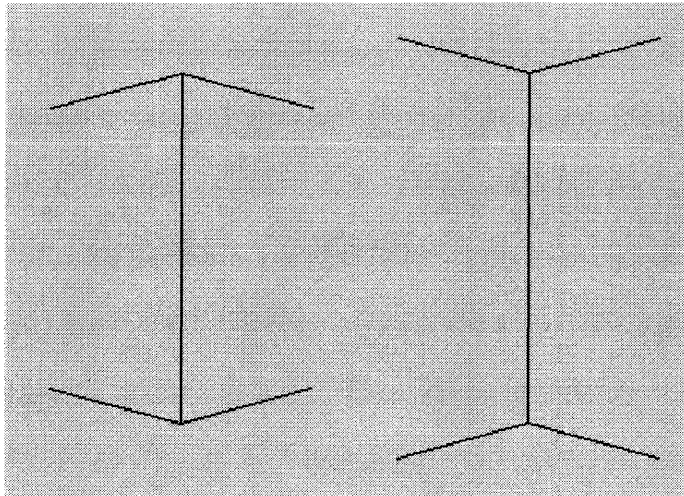


Fig.3.4. The Muller-Lyer illusion is so called because the line with the outward drawn wings tends to look longer than the line with the inward drawn wings. It is an illusion because the lines are actually the same length.

The Muller-Lyer illusion is easily demonstrated. Figure 3.4 shows two horizontal lines containing a pair of "wings." The wings are drawn outward or inward from the line ends. The illusion is that the line with the outward drawn wings tends to look longer than the line with the inward drawn wings. It is an illusion because the lines are actually the same length.

One of the most popular explanations for the Muller-Lyer illusion is that our brain makes mistakes about the relative depths of the two lines. We are used to seeing outside corners of buildings with lines sloping inward away from them (whereas

the Zulus are not). In these situations, the brain knows that the line running down the outside corner is the closest part of the image to us.

The brain realises that this line is really shorter than it appears when compared to the rest of the building. We are also used to seeing the inside corners of rooms with the lines of the roof and floor sloping outward away from them. In these situations, we know that the corner is the furthest part of the image from us. The brain realises that this line is really longer than it appears when compared to the rest of the room. When the brain compares lines from these two situations to each other, it reduces the size of the line with the inward sloping tails (the corner of the building) because it thinks this line is closer to us. It increases the size of the line with the outward sloping tails (the corner of the room) because it thinks this line is further away. This makes the line with the outward facing tails look longer.

3.4.3 The Necker Cube

An example of top-down dressing is the “Necker cube” and it is our knowledge of light and shadow that presents us with no problem in interpreting Figure 3.5 as a cube. In the 3D “wire-frame” test used in the second phase of testing in this present research, each shape consisted of 10 such rhomboids joined together. If we look at a wire-frame representation of the same Necker cube, it is argued that our cultural knowledge of the “carpentered world” and of the representation of perspective in two-dimensions allows us to interpret the object as a cube as in Fig. 3.5 b.

The problem lies in the fact that although the picture is representing a three-dimensional object, there is insufficient information to determine which is the

front and which are the back faces of the cube. More detailed information would include occlusion, perspective convergence or texture. At one moment the rhomboid's orientation appears to be such that the front face looks as if it is pointing down and to the right. In the next moment, there is a reversal in depth and it looks as if it is pointing up and to the left. For most people, they will constantly swap between the two possible interpretations. As Wade and Swanston (2001) explained "pictures can incorporate ambiguities that are rarely present in objects" (pg.28). In this particular example it is depth, as represented by the line drawing, which is ambiguous.

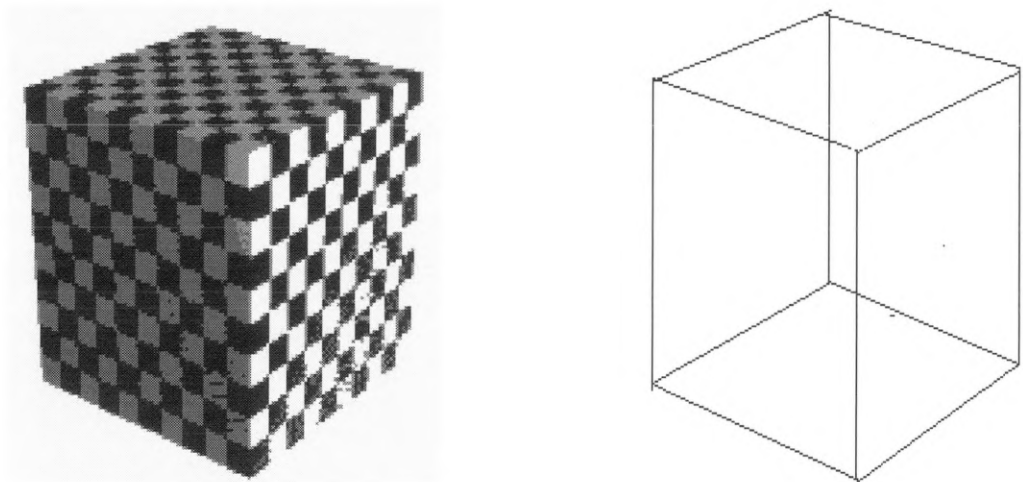


Fig 3.5 shows two representations of the Necker Cube, one shaded (a) the other wire-framed (b). In the latter there is insufficient information to determine which are the front and which are the back faces of the cube, thereby creating ambiguity.

In a western culture we would have no difficulty in looking at a picture and interpreting it as having, for example, a hunter in the foreground and an elephant approaching the hunter from a distance. Gregory however, tells of people who inhabit dense forests and therefore never experience distant objects. By taking

them out of the forest and then showing them distant objects, they see them as small and not distant, therefore the elephant in the picture would be perceived as being very small rather than in the distance. In our own Western culture we have experienced objects looking small, for instance, when viewing people on the ground when seen from an aeroplane, Gregory would therefore argue that we have learned the association between size and distance.

3.4.4 A Computational Model Of The Mind

Pinker (1997) however, argued that we should not make so much of culture and he tells of the isolated cultures that are unable to interpret photographs of faces as they see them as little more than smudges. It is only after they have received training in how to interpret the pictures, can they finally see the “three-dimensional” face. Pinker described such claims as “social-science folklore” and refers to Paul Eckman’s work with New Guinea Highlanders who are totally cut off from the world. These remote people were perfectly able to recognise the facial expressions in the photographs they were shown. In Pinker’s own words:

“Lost in the brouhaha was a more basic discovery: that the New Guineans were seeing things in the photographs at all rather than treating them as blotchy grey paper” (pg 215)

Pinker further disputed cultures influence in the interpretation of perspective drawings. His own words are again the most fitting:

“Surfaces are evenly coloured and textured... so a gradual change in the marking on a surface is caused by light and perspective. The world often contains parallel, symmetrical, regular, right-angled figures lying flat on the ground, which appear to taper in tandem; the tapering is written off as an effect of perspective. Objects have regular, compact silhouettes, so if Object A has a bite taken out that is filled by Object B, A is behind B; accidents don’t happen in which a bulge in B fits flush into the bite in A.” (Pg 215)

Pinker was therefore explaining our understanding of perception from a combination of a computational model of the mind and evolutionary psychology. He believes that the human mind has developed a number of specialised modules for performing specialised tasks during the course of our evolution. One such task is the interpretation of perspective and therefore challenges the Standard Social Science Model that emphasises the formative effect of culture. Pinker claims that:

“whatever assumptions impel the brain to see the world as the world and not as smeared pigment will impel it to see the painting as the world and not as smeared pigment”.

3.5 Familiarity And Shadows.

Further monocular clues to depth are previous familiarity and shadows. The former cue is the size of an object. When a scene contains objects of a known size, the relative size is used to make an estimation of distance. With regards to the latter, most objects in the world do not allow any or little light to pass through them, therefore these objects cast shadows. Shading and shadows are important depth cues. Shadowing and texturing are important to the design of VEs, as they are needed to ensure images look as lifelike as possible. In a non-immersive environment, shadowing is easier as the viewer knowingly views the image on a display therefore it is not necessary for the image to have such a precise shadow. It is therefore the viewers perceptual skills that carry some of the processing load. In a virtual world, particularly if fully-immersive, the intention is to create a much more lifelike environment, ideally to the point where the viewer should not be aware of being in a computer generated world ((Mills and Noyes, 1999).

In the real world the exact shape and description of shadows change depending on the direction of the light. The motion of the sun across the sky causes surfaces

within the environment to be illuminated differently during the day. Surfaces that are under high illumination early in the day will be under low illumination late in the day. When outside, in the morning, shadows are long and are cast in a westerly direction, short and northerly at noon and in the late afternoon they are long but are cast to the east. However, there are certain rules about shadows. In a place with only one source of light, the sun being the primary source of light outdoors, the shadows from all the objects in the area all go in the same direction.

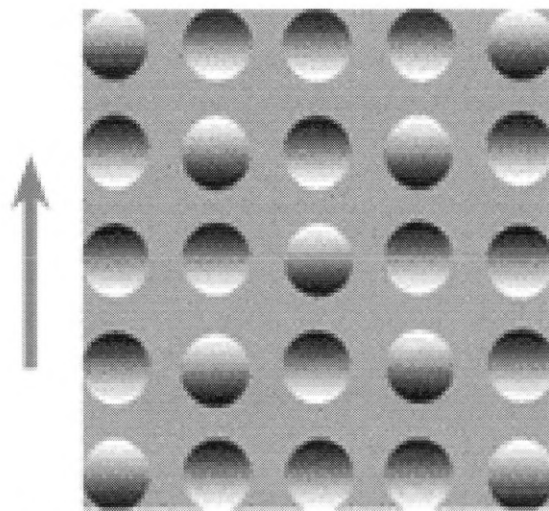


Fig. 3.6. The shaded circles seem to form an X made of spheres. But if you rotate the image 180°, the same circles form an X made of cavities. Picture after Ramachandran (1988).

How the natural illumination of the sun influences perception can be clearly seen in Fig.3.6 that shows a number of convex and concave shapes. Which of these spheres are perceived as convex depends on their shading? According to Ramamchandra (1988a) our visual system tends to assume that there is only one light source and that it comes from above. A sphere with a shaded bottom half will be perceived as convex but if the upper half is shaded, it will be seen as concave. Rotating the figure 180 degrees will make the convex spheres now appear concave and vice versa. In relation to assuming that the sun shines from

above, Ramachandran (1988b) asked how does the brain know “above” from “below”? He gave the following experiment to illustrate the answer:

“Lie on a couch and let your head hang over the edge so that you are looking at the world upside down. Now ask a friend to stand behind your head and hold the lower illustration [fig 3.7] ...upright. The objects in group a will look concave and those in group b will look convex; that is, you get the same effect as you did when you rotated the page.”

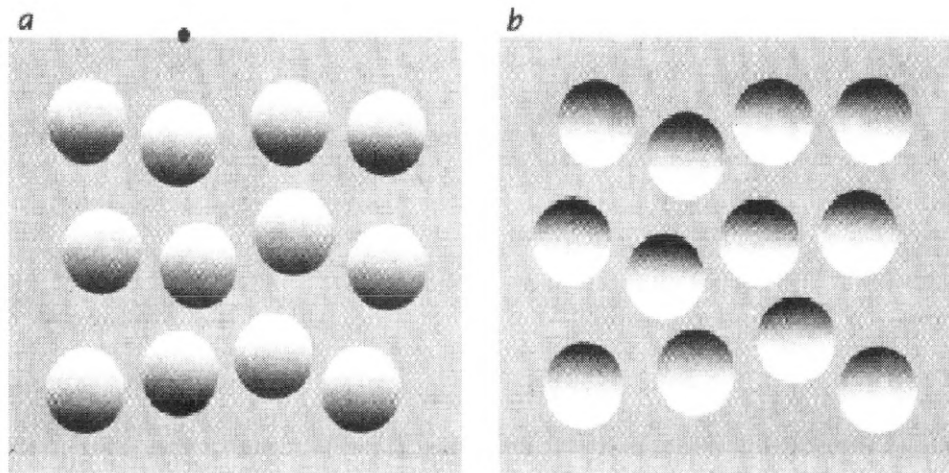


Fig 3.7 According to Ramachandran, the brain assumes light comes from above, therefore the objects in group *a* appear convex, whereas those in group *b* appear concave. By turning the page upside down, the objects will reverse in depth. Turning your head upside down and looking at the picture will show that it is the orientation of the pattern on the retina that matters. (After Ramachandran, 1988)

Ramachandran explained that it is the orientation of the object on the retina that is important and not your objective knowledge of up and down that effects your perception of depth. He emphasised the importance of shading for depth perception, however, he stated that shading only gives a weak impression of three-dimensional shape but when a shaded surface is enclosed by an outline, this gives a credible impression of depth. By adding an outline or border, any information from ambiguous shading cues is resolved, demonstrating that the brain recovers information about the shape of objects by combining outlines and shading cues.

In the “Solid” 3D test, used in this present study, shaded shapes with the added bonus of having outlines will be used to test mental rotation ability.

3.5.1 Countershading

Shading is thought to be a primitive mechanism as Thayer (1909 cited in Gephard 2001)) stated that in the natural world, animals have evolved the principle of countershading. Countershading is a pattern in which the top of the animal is darker in colour than the bottom. This is the opposite of the shading pattern produced by sunlight, which is always light on top and dark on the bottom. Since this shading pattern is what makes us see an object as three-dimensional, countershading tends to make an animals body look flat. If the animal stands very still, this can confuse or fool a predator.

In the case of a shark, countershading is a form of protective colouration in which they are darker on their upper (dorsal) surface than on their lower (ventral) surface. Many sharks, especially those that live near the surface, are a dark colour on their backs and a lighter colour on their bellies. The countershading camouflages them from two directions -- looking up at them against the surface, and looking down at them against the sea floor. Lighting from above casts a shadow below and countershading therefore reduces contrast, producing a more neutral density when viewed from above, which is a typical vantage point of a larger or aerial predator. Keffner and Ramachandran (1992) suggest that countershading is successful because of its ability to reduce the extent to which an animals shape “pops out” from the background, such an effect can only be observed for top-bottom differences in shading. Countershading can be clearly seen in the shark in Fig. 3.8

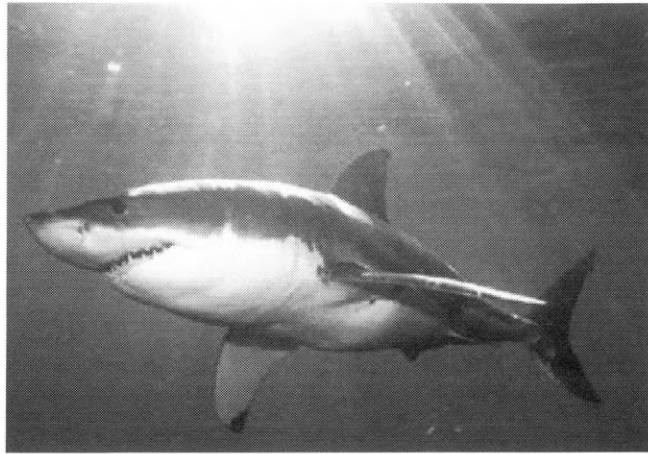


Fig 3.8. An example of countershading on a shark.

3.5.2 Shading and motion perception

Kleffner and Ramachandran (1992) looked at whether or not shapes that are understood solely through differences in shading can be used by the visual system to establish motion correspondence. The ability to perceive an intermittently visible object as being continuous motion means that the visual system must be able to detect correspondence. Ramachandran and Anstis (1986) define this as being able to determine which parts of successive images reflect a single object in motion. If each image in a series of images differs only slightly from the one immediately previous, the visual system will be able to detect motion. However, if the successive images are vastly different, there will be no illusion of motion. In nature, anything that moves are usually a predator or a prey therefore it would be of evolutionary advantage to have mechanisms that are able to quickly detect such movement.

Ramachandran and Anstis (1986) studied apparent motion and found that the brain first computes three-dimensional shape long before it perceives apparent motion, which is the illusion of continuous motion. The makers of television

programs, motion pictures and virtual reality exploit this illusion. When presented with a rapid series of still images, the visual system fills in the gap between each image or frame, as though it is seeing an object or event in continuous motion.

Kleffner and Ramachandran (1992) stated that the visual system extracts a three-dimensional object from its shading cues first and then the perception of movement is based on the three-dimensional image and not the primitive two-dimensional image. Results from their research showed that participants were able to predict the direction of motion more accurately when the direction of shading was vertical rather than horizontal. This supports their previous findings that the extraction of shape from shading can contribute to motion processing. Kleffner and Ramachandran advise that these results show that shading, which is a monocular depth cue, *“can drive the motion system, which is usually regarded as an early...visual process.”* (Pg 33).

3.5.3. Can Shape From Shading Prevent Us From Falling Over?

A question raised by Kleffner and Ramachandran was, could the shape from shading system have evolved as a primitive visual module to control locomotion and prevent us from falling over? They asked this due to an effect they observed when studying background luminance on perceptual grouping and pop out. They found that segregation was optimal when they *“used a neutral grey background whose luminance was identical to the mean luminance of the shaded tokens”*(pg 34). This, they say, suggests that the visual system also makes the assumption that the background has the same reflectance characteristics as the objects in the foreground or in other words, they are both made of the same material. Clearly, this is not generally true for most objects but it is true for “lumpy terrain”. Being

able to distinguish shape from shading would enable us to tell the difference between a mound and a hole when crossing the aforesaid lumpy terrain. Locomotion could be controlled by either jumping over a mound or walking around a hole. That humans can perceive depth from an early age can be illustrated by briefly considering the classic “visual cliff” experiment where a baby is encouraged to crawl over a “hole”.

3.5.4. Perception of depth is a hard-wired function.

Gibson and Walk’s (1960) classic visual cliff experiment showed that very young babies are able to perceive depth. The experiment comprised of having a child placed upon a raised area, on a sheet of glass covering black and white squares (See fig.3.9). On one half of the area, the black and white squares were one meter below the glass rather than immediately below. They found that babies as young as 6 months were very reluctant to crawl over the ‘cliff’ even when their mothers encouraged them to do so. It could be argued that children of that age had already learned depth perception so the experiment was carried out using animals such as chickens, kids and lambs, all of which are capable of walking as soon as they are born. They too refused to cross the cliff, indicating that depth perception is an innate rather than a learned function.

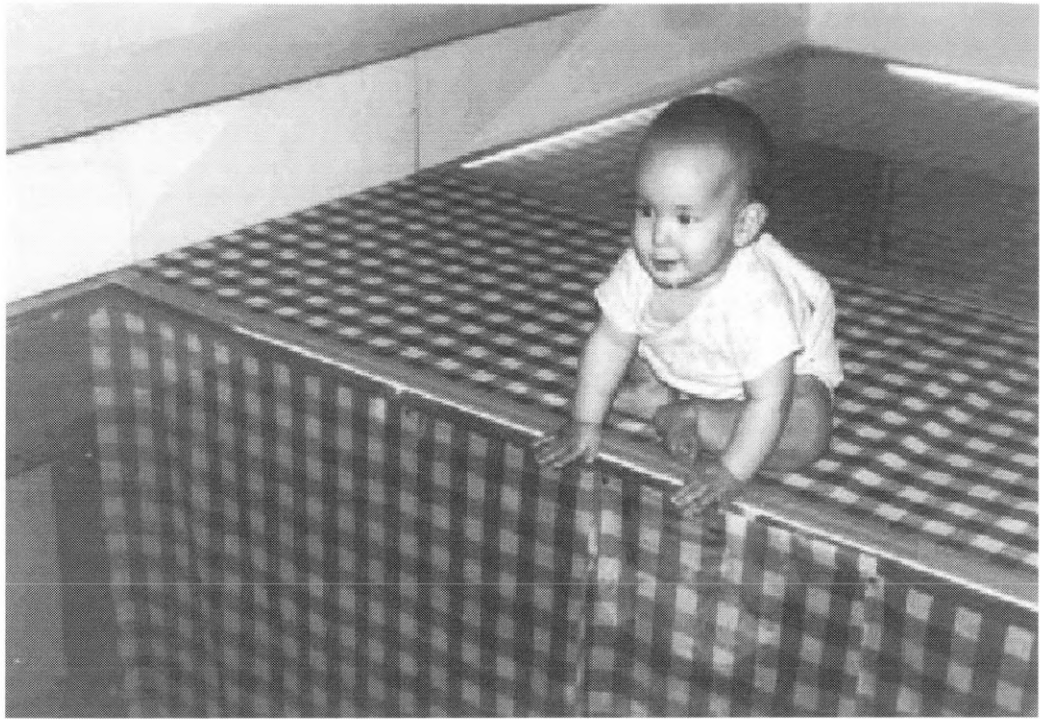


Fig 3.9. Shows the Gibson and Walk's (1960) classic visual cliff experiment showing that babies as young as six months can perceive depth and refuse to cross the area of glass where there is a meter drop below, despite encouragement from their mothers.

3.5.5. Underlying Neural Mechanisms

A study by Hanazawa and Komatsu (2001) also looked at the assumption that natural and artificial light sources are usually positioned above the viewer when looking at an object or scene. They showed that neurons in the visual area known as V4 are adapted according to this bias, therefore deriving three-dimensional structure from shading cues. The visual area V4 is an intermediate stage in the object-processing pathway of both human and non-human primate brains.

Using squares of shaded texture elements, similar to those found in Ramachandran's experiments, they found that many texture responsive cells are tuned for gradient direction, with the greatest response rate, in action potentials per second, corresponding to vertical gradients with bright above and dark below.

Their statistical tests revealed that the bias towards vertical gradients was significant. They concluded by saying that the correspondence between neural functions and the environment suggests that the cells are used in three-dimensional texture perception based on shading cues. The vast number of cells that are tuned for vertical gradients might explain why we are better able to discriminate textures that are, or appear to be lit from above.

3.6 Motion Parallax

When designing a virtual environment, the designers try to create an interface representing information that is as close as possible to the real world. This creates many a problem, as they have to create graphical techniques to develop three dimensional scenes and objects. These problems include a 'motion parallax' technique that models a two-dimensional scene to appear to be a 3D object. Motion parallax can be described as being when the eye changes position, the retinal images of the points at different distances move different amounts across the retina, providing a cue to their depths (Fig 3.10).

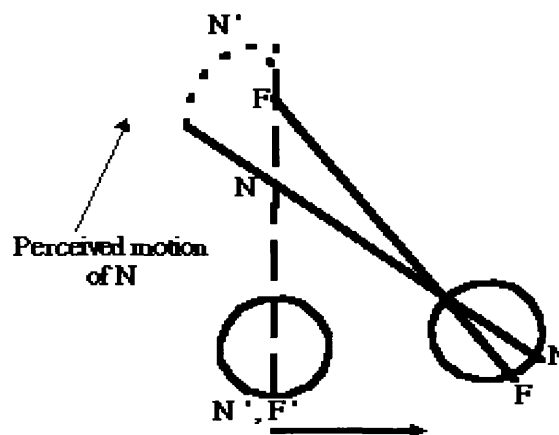


Fig.3.10. shows that when the eye changes position, the retinal images of the points at different distances move different amounts across the retina, providing a cue to their depths

This can perhaps be better illustrated by looking at Fig.3.11 that demonstrates that when the figure moves from P1 to P5, the relative locations of the man, the tree and the house change.

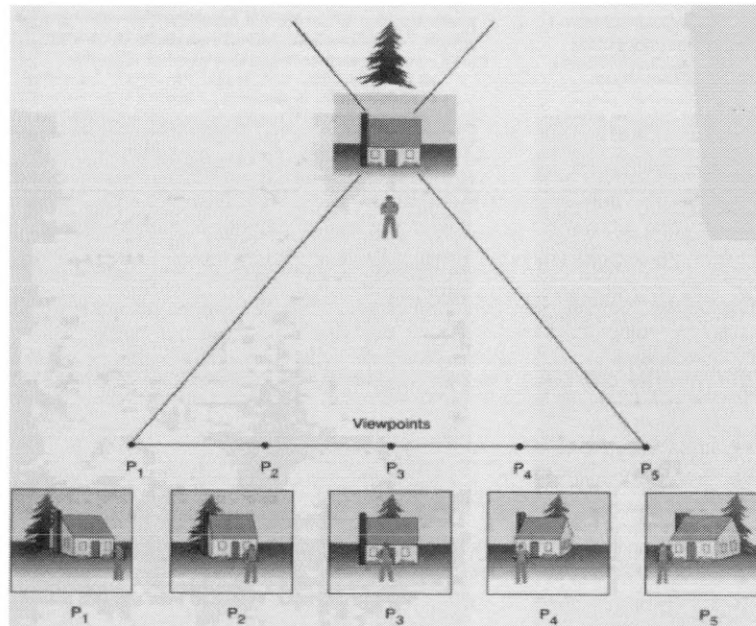


Fig 3.11 shows that when the figure moves from his location at P1 to his location at P5, the relative locations of the man, tree and house change, this is called motion parallax.

3.7. Stereopsis

The most powerful impression of depth, particularly when looking at photographs, films and virtual environments, comes from stereoscopic or binocular cues. Stereopsis is based on convergence of images on the retina of each eye.

When looking at a fixation point, the eyes converge so that the fovea of each eye is focussed on that point. However because the two eyes are separated in space, by about 6cm for humans, the image falling on each eye is not identical, as can be seen by alternately closing each eye while fixating the end of your finger and observing the background. All objects that lie at the same distance from the observer as the fixation point are said to be on the fixation plane. For objects lying

closer or further than the fixation plane, the same part of an image does not lie on corresponding parts of each retina. Comparison of the position of the images on each retina provides a cue to the distance. If the two images are both located towards the nose on the retina compared with the fixation point, the object will be interpreted as being closer than the fixation point.

The single image that is perceived by fusing the image from both eyes is an illusion, created by combining parts of the image that are on separate places on the retina. This binocular disparity, the difference between the two images, leads to a subjective impression of depth. Because the eyes are separated in space horizontally but not vertically, only horizontal disparities on the retina produce stereopsis. Shutterglasses, as used to view the 3D MRTs and the VE in this present study operate on the same principle (see chapter five for a fuller description and illustrations)

3.8 Navigation Within A Three-Dimensional Environment

The ability to perceive objects in space and to have an understanding of depth are, in themselves, of little use to us as moving agents in the world if time is not added to the equation. In other words, motion means a change in spatial location. Wade and Swanston (2001) explained that: “Retinal image motion can be a consequence of displacement either of the object relative to a stationary environment or of the observer relative to a stationary object.” (Pg, 129) Of course, both the observer and the object could move together, for example an observer could be sitting in a moving car whilst looking at a pedestrian walking in the opposite direction. Such conditions change the pattern of stimulation at the eyes therefore movement is

characterised by subtle but highly structured changes in retinal illumination over space and over time.

Wade and Swanston go on to advise that, “visual motion is mediated by stimulation of the retina whereas motion perception is not synonymous with retinal motion.” Motion perception is vital for navigation and in virtual reality systems the problem of sensory conflict has been the focus of a great deal of research.

3.8.1 Sensory Conflict.

Theories relating to the causation of simulator sickness suggest that some of the effects may be produced by sensory conflict between the visually induced sense of motion, which is calledvection and vestibular and proprioceptive cues indicating non-movement. If such conflict should occur, users of VR might report and display symptoms of nausea, disorientation, dizziness and postural instability.

Howarth and Costello (1996) studied the effects of VR systems and the associated onset of symptoms that are similar to simulator sickness. Sensory conflict has been used to explain these symptoms (Reason, 1974) and occurs when signals from the spatial senses - the eyes, the balance organs, and the non-vestibular position senses - are in conflict, and do not correlate with signals received in previous experience. A possible cause of the onset of symptoms, when using immersive VR, is the visual lag which occurs when the user makes a head movement. In the real world, a head movement results in either an immediate compensatory eye-movement or a change in the retinal image allowing the brain to distinguish between head and eye movements and the movement of objects.

When using a VR headset, a delay is introduced when information pertaining to a head movement is analysed and the screen image recalculated. Any reflex ocular movement which, occurred as a result of the head movement, would have occurred before the screen image was up-dated, causing momentary confusion. Lag varies considerably between systems as it is a function of processing power and may be as low as <10ms but in the case of inexpensive systems that are PC based, the lag increases significantly.

Howarth and Costello also point out a second area of concern which is where optical flow information conflicts with vestibular information. They state that problems may arise if the user is able to move around the virtual environment using buttons or gestures rather than real movements. As movement occurs, optical flow past the eyes of the “traveling” user in the environment suggests movement, whereas the vestibular organs indicate that little or no movement is taking place.

They give the example,

“ one can consider the situation where a user can 'fly' through the virtual environment by using a hand control rather than having physical movement. If one assumes that the equipment does not have a motion base, it is clear that the balance and position senses will experience none of the movement that is suggested by the visual senses. The senses then generate conflicting messages to send to the brain and it is this 'sensory conflict' that has been cited (Regan, 1995) as a potential cause of simulator sickness symptoms in users.”

The third area of concern, which they refer to, is where movement of the virtual world is inappropriate for the physical movement made by the operator. For instance, if a user makes a head movement of 45 degrees but the virtual world moves through an angle of 90 degrees. Such an experience would not occur in the

real world and may cause the user to experience psychological problems, such as disorientation, as well as the physiological feeling of nausea.

3.9. Navigational Awareness

Navigational awareness can be defined as having a complete navigational knowledge of an environment (Satalich, 2000). Navigating takes place in many different situations such as driving across a country, walking in a city or simply finding ones way throughout a building. In all of these cases, people are using common sense knowledge of geographic space (Raubal and Egenhofer, 1998) There are two main types of spatial knowledge that are required when people engage in spatial learning, procedural knowledge and configural knowledge. Procedural knowledge can be divided into knowledge about landmarks or reference points and route knowledge. Over the years there have been a number of models that have attempted to describe the way in which humans encode navigational features of an environment (Downs & Stea, 1973; Lynch, 1960; Siegal & White, 1975). As with all models, there are discrepancies between them, however, there is a general overlap in the area of the three distinct stages that have become associated with the way in which humans internalise a given environment. The main features of building a cognitive spatial representation of a novel environment can be divided into three sub-goals:

Sub-goal one:

The spatial representation of a given environment enables the navigator to identify their current position therefore aiding locomotion whilst avoiding getting lost or disorientated. The above model shows that the first step towards constructing a complete spatial representation requires the navigator to at first discriminate landmark information from the environment. Landmarks are external points of

reference, which are used as devices for maintaining course (Siegal and White, 1975). Landmarks or reference points have some unique quality that distinguishes them from the rest of the environment. They can be as diverse as a place the navigator associates with a special activity, the colour or texture of floor coverings or indeed to distinctive light patterns. Therefore landmarks are salient cues, which are static, orientation dependent and entirely disconnected from one another.

These distinctive features of a spatial layout can be used as a basis for making judgments about various aspects of the environment. Auditory and olfactory stimuli can also be used as landmarks, such as would be found at a busy fish-market (Lynch, 1960). Further, a distinction can be made between a landmark and an anchor point, the former being spatially significant to most people i.e. a tower or distinctive building, the latter being spatially significant only to an individual i.e. the girlfriends house. It is therefore important to understand that human beings do not separate emotion from their movements in space. We revisit places we like, and avoid places we don't like, especially if they pose a threat or unpleasantness. Landmarks, if they have any kind of emotional association, are more easily remembered, and more easily used as navigational references, than are landmarks to which we are indifferent.

Lynch's work is thought of as the foundation for human way-finding research and is used primarily in city design. To aid navigation, his city designs are divided into images of paths, edges or boundaries, regions and landmarks. Important, is the concept of "imageability" or finding the quality in a physical object which

gives it a high probability of evoking a strong image in any given observer” (Lynch 1960, pg 9).

An emotional representation of space or an affective map is more significant than the cognitive or mental map (Spencer, Blades and Morsley, 1989). For a landmark to be effective as a navigational aid, it should have emotional content, a functional place in the environment, a spatial relationship with surrounding landmarks and it should have sensory attributes such as tone, pitch, colour, texture, size, shape, etc.

Venison (1999) wrote a comprehensive literature review on how landmarks should be used in VR environments. He understood the significant role that landmarks have when encoding spatial information and suggested that they should be distinctive and salient. In particular he said they should be high enough so that they can be seen from all perspectives and should be bright and colourful enough to stand out from other potential landmarks. By making the landmarks concrete and familiar i.e. church or car, rather than abstract such as a painting, the navigator would find it easier to remember. In order to help orientate the navigator, the landmark should be designed so that each side should appear different, thus allowing the navigator the ability to easily discern their current position in the environment from the aspect at which they view it. From a symmetrical landmark it is harder to ascertain an exact position, as it would look the same from several locations. Landmarks would therefore have to be positioned at major junctions where the navigator is likely to make major decisions with regards to orientation. Landmarks located between junctions are

more likely to be used as markers to confirm that the navigator is traveling in the correct direction.

Sub-goal two

Once the navigator has distinguished landmarks, it is then possible to learn route formations or pathways from one landmark to the next. Route knowledge is ego-referenced and normally the navigator will gain such knowledge by exploring the environment personally. Route knowledge therefore refers to the spatio-temporal relations between specific environmental features. Landmarks are therefore put into a sequence or navigational paths. When the navigator reaches a landmark they then recall the necessary direction to take in order to continue their journey.

Siegal and White advise that landmarks punctuate routes thus reducing the cognitive load required to remember the entire route. Any irrelevant stimulus that the navigator encounters on route can be ignored such as the absolute or indeed relative distance being traveled, shop names, number of junctions, etc. It is really only the recognition of landmarks en route that allows the navigator to know that they are on course. The relationship of the landmarks is also unidirectional therefore making it difficult for the navigator to retrace their steps as the landmarks have been learned from A to B and not from B to A. Darken and Peterson (2002) suggested that route knowledge can be thought of as a graph of nodes and edges that is constantly growing as more nodes and edges are added.

A navigator may build up a model of an environment, for instance, their hometown, by discovering a number of different routes to the town centre. In other words they have built a model from procedural knowledge, whereby they

have developed a series of sequence based routes within that environment. At this stage the navigator is able to make their way along a known route but has not yet formed spatial relationships. This means that they would not be able to recognise alternative routes or short cuts. Procedural knowledge therefore uses little theory and is task specific in nature allowing little opportunity for transferring such knowledge to different situations. A navigator with route knowledge may, however, know the approximate distance between landmarks as learning has been due to sequential travel.

Sub-goal Three

Survey knowledge refers to map like structures that include information about the inter-relationships among locations. Knowledge is reached when the navigator is aware of the spatial relationship between landmarks. Route knowledge allows the navigator to locate landmarks and routes within a general frame of reference, which include Euclidian measurements. Cardinal directions and metric distances serve as coordinates to map spatial relationships among distinctive locations within a network of routes.

Developmental evidence suggests that the encoding and retrieval of landmark knowledge may precede other sorts of spatial knowledge and that way finding is a natural skill that people learn as small children and develop as they mature (Piaget and Inhelder, 1967). Procedural knowledge is egocentric and sequence based whereas survey knowledge is spatially structured, more like a map. Survey knowledge is characterised by the ability to take an exocentric viewpoint and is therefore world referenced. In other words the mental representation of the environment is visualised as though seen from a birds eye point of view. This is

referred to as having a cognitive map. Using survey knowledge, the navigator tends to remember routes as being straighter and junctions as being more right angled. Other tendencies are grouping things closer to the landmarks and remembering relative rather than specific positions (Lynch, 1960).

Survey knowledge built through personal experience is referred to as “primary” experience, whereas that learned from maps or pictures is called “secondary” experience, the latter being inferior to the former. The inferiority is due to the orientation and location of landmarks. If the navigator has both procedural and primary survey knowledge, they can have complete navigational awareness therefore routes can be inferred even although never traveled by the navigator. In other words, once route knowledge has been attained, the navigator will not only know the route from A to B, and from B to C but can infer a direct route from A to C. The reason for this is because the navigator now has the ability to estimate relative distances and directions between any two points.

3.9.1 Models Of Spatial Awareness And Navigation.

A spatial awareness model put forward by Siegel and White (1975) called the Sequential and Hierarchical model showed that a navigator has to go through a constructive dynamic process in order to complete their navigational knowledge of a novel large-space environment.

1. Landmark recognition.
2. Route knowledge.
3. Primary survey knowledge, achieved after significant traveling of routes and links to the point where alternate routes can be inferred.

4. Secondary survey knowledge involves using maps to learn about an environment.

5. Chunking of the environment. Chunking occurs if the environment is particularly large and it is necessary to break it down into smaller regions that are nested within larger regions i.e. learning several neighbourhoods that can be nested under a town. The nesting ability allows the navigator to mentally zoom in and out of a representation to give distance or direction to another target however zooming out loses detailed description (Wilton, 1977).

Darken and Peterson (2002) attempted to explain how navigation tasks are constructed by using Jul and Furnas (1997) model of navigation (see Fig 3.12).

They describe how the model works:

“I’m at the shopping mall and decide I need a pair of shoes. I have just formulated a goal. Now, how should I go about finding shoes? I decide to try the department stores. Department stores are typically on the far points of the mall. I have just formulated a strategy. The next step is to gather information so I don’t walk off in a random direction. I decide to seek out a map of the mall. I am acquiring information and scanning (perceiving) my environment...I view my surroundings, assess my progress towards my goal, and make judgments as to how to guide my movement. At any time in this loop, I may decide to stop looking for shoes and look for books instead. This is a change in goal. I could also decide to look for a small shoe store instead of a department store. This is a change of strategy. In any case, the task continues, shifting focus and process as necessary.” (Pg 6)

and go on to say that navigation is a situated action in that planning and the carrying out of any given task are not serial events but are necessarily entwined in the context of the situation. The environment, the navigator and the task in hand cannot be separated.

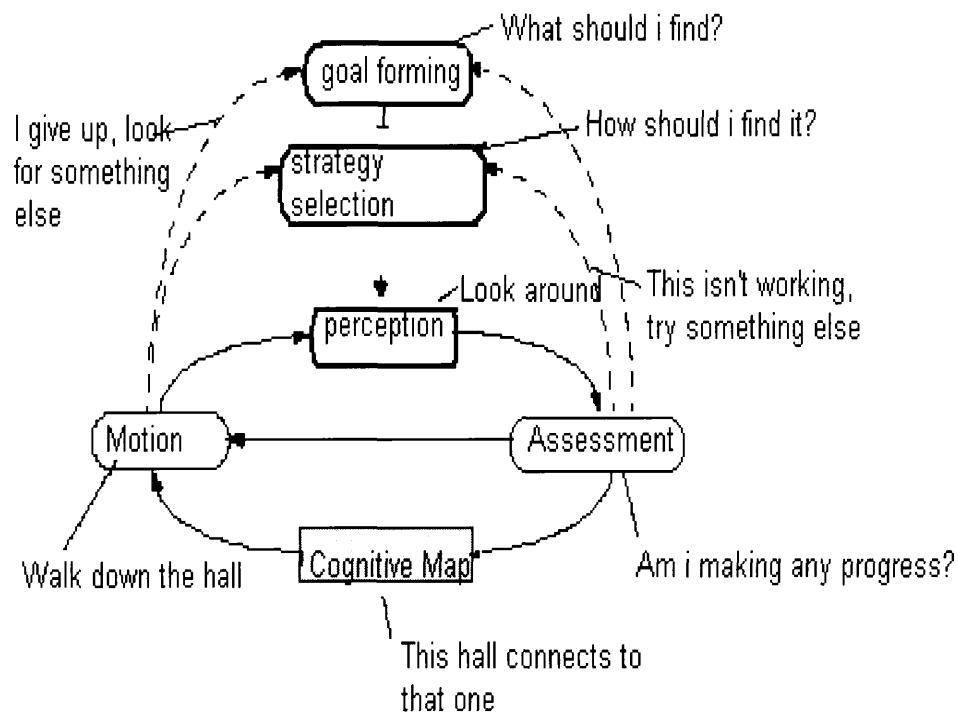


Fig. 3.12. A model of navigation, after Darken and Peterson (2002)

3.10 Cognitive Maps

There is an assumption that humans have fully coordinated and complete mental representations of the environment. Psychologists use the term “cognitive map”, even although a number of authors state that the term is highly misleading as it assumes a map-like mode for representing space (Hart and Moore 1973). The cognitive map metaphor suggests a mental representation that corresponds to a persons perceptions of the real world. The cognitive map develops from a mental landmark map to a mental route map and eventually results in a mental survey map. The last stage, although containing inaccuracies and distortions, can still be likened to a cartographers map. People construct and develop their cognitive

maps based on re-coding old information through perception, natural language and inferences. Complex environmental structures can lead to the slower development of cognitive maps and also to representational inaccuracies (Reubal and Egenhofer, 1998)

It is generally accepted that humans have the potential to acquire a representation of their environment, but quite how such a structure is developed during the learning process is still under debate. There are two major theories concerning the way adults construct mental representations of space over time, the first by Siegal and White, and the second termed “the information processing account”.

3.11 Siegal and White model

Siegal and White (1975) proposed that adults construct cognitive representations of the physical environment at two levels. Over repeated direct experience of an environment the navigator constructs a sequence of landmarks, which identify a specific geographical location, and is linked into a given route. A route, they claim, comprises of non-stereotypic sensori-motor routines for which one has expectations about landmarks and other decision points. This then is the minimal basis for a mental representation of space thus aiding navigation and way finding.

Siegal and White make a clear distinction between way finding and navigation in that way finding is a special case of navigating. Lynch (1960) defines way finding as based on “*a consistent use and organisation of definite sensory cues from the external environment.*”(pg.3). The ultimate goal of human way finding is to find the way from one place to another. The space in which human way finding usually takes place is called large-scaled space, in that objects which

cannot be moved because they are larger than people, requires people to navigate through large-scale space in order to learn about them. Examples of large-scale space are landscapes and cities.

Darken and Peterson (2001) described way finding as being the cognitive element of navigation, such as the tactics and strategies in guiding movement. Way finding not only precedes movement but also is coupled to it in order to navigate successfully, therefore the development of the cognitive map or mental representation of the environment is crucial. They go on to say that a cognitive map is not purely based on imagery but also has symbolic content. Navigation, on the other hand, is the combination of both way finding and motion, putting together both the cognitive and motor elements.

Active experience in the environment is crucial for the construction of spatial representations and for the gradual integration of their parts. A landmark has a specific role in the context of the navigators interactions with the environment. This has been termed 'recognition-in-context-memory' on the assumption that the brain attends to, and records, meaningful events such as the appearance of a place that is important in way finding.

A sequence of landmarks can only become a route if it has the addition of directional information that can be associated with each landmark. The minimal form that this might take is a Stimulus-Response reaction that specifies the direction that the navigator must take in order to reach the next landmark in the sequence. The stimulus being the landmark and the response being the paired

action i.e. turn right. Such a route would constitute a '*sensori-motor routine*' (p.24) with the distance between landmarks being left unspecified.

Any two landmarks not connected by an established route segment could not be inferred. This is like the topological representations of the pre-operational child as formulated by Piaget in his theory of child development. In Piaget's theory, a pre-operational child can represent order etc. but cannot accurately represent the distance between locations.

At the second level, Siegal and White state that knowledge represents patterns in two or three dimensions in that all spatial representations are functionally landmarks-connected-by-routes but that there are varying degrees of integration of the spatial representation. As an adult gains experience of the environment, a number of different routes and their relative distance are gradually incorporated into their schema. This scaling of the environment permits the specification of the bearing between any two points on a single route, whether or not these were adjacent points in the sequence. Where two routes share one or more common landmarks and assuming that the scaling is more or less uniform across all routes, one can infer bearings between points not shared by any two routes.

Siegal and White see this process as the first step in the co-ordination of routes into a survey-like representation. Configurational representation comes, as suggested by Piaget, at the onset of formal operations. Research by Golledge (1992), would argue that there are two different types of route knowledge, that which is declarative and that which is more at an unconscious level. In the case of

the former, the navigator would learn distinct facts about a particular route. In the case of the latter, as the navigator becomes familiar with the route, these facts become proceduralised, whereby action is guided with very little conscious effort. An example would be a driver traveling a well-worn route. In time, long distances can be traveled whilst the drivers mind is preoccupied with thoughts other than navigating and driving, i.e. driving on automatic pilot. Both types of knowledge are capable of integration into a more global representation.

Levine, Jankovic & Palij (1982) carried out studies to test the proposition that when a navigator learns a series of points sequentially, they automatically place these points into a cognitive map. The relationships among all points whether they are new relationships or old, are then equally available (p. 163). This 'equiavailability' hypothesis predicts that it is possible to read off the spatial relationships between any pair of points with equal ease, whether or not the pair was sequentially linked on the original path.

Participants in their study were blindfolded and asked to learn a route divided into three segments by walking the route a number of times. The 'equiavailability' hypothesis was put to the test in that participants were asked to walk between pairs of points on the original path, and also to carry out shortcuts between points not linked on the original path. It was found that the accuracy of the participants walking estimates were the same for old and new paths. The authors interpreted the results as supporting the notion of a picture-like cognitive map. If participants took longer to respond in the shortcut condition this might indicate that they were

not using a map like representation but were in fact calculating the new route segment from a propositional representation, which is more route based.

3.12. The Information Processing Account

Siegel and White's theory is associated with the 'map in the head' metaphor however, Hart and Moore (1973) suggested that Piaget's Stage IV, which is a fully coordinated representation including coordination of perspectives and a metric coordinate framework, was never fully achieved. They argue that human spatial representations are to some extent centered on and influenced by places and objects in the world.

Carreiras (1986) claimed that the theory that Euclidean geometry underlies the spatial representation of the relations between all locations could not be defended (p. 76), suggesting that an information processing (IP) or problem solving account, more adequately explains the ultimate level of spatial representation in humans.

According to the IP account, knowledge is organised hierarchically and schematically. There are different levels of abstraction and different modes of representation thus maximising the power of spatial thought while economising on what is after all a limited working memory capacity. The representational mechanism must also support what Kuipers (1982) called states of partial knowledge that inevitably arise in a system operating under processing limitations. Such a system cannot devote its processing resources to spatial data all of the time and therefore the resulting representation will be fragmentary and include mistakes and hunches. Cognitive heuristics may well be applied to spatial

data therefore allowing faster and more efficient processing within the limitations of the system.

Piaget assumed that an adult would possess a complete and metrically coordinated representation. However, as far as the IP account is concerned, this would not make computational sense, especially in an environment where a human has to make fast and relatively reliable spatial decisions on the basis of knowledge that may in fact be incomplete or incorrect. A single metric representation would require a high degree of accuracy, which does not allow for fragmented or partial knowledge. Should a mistake occur on such an accurate representation, this would be at great cost to the system for it would be necessary for readjustments to be made to large portions. An example would be if a view of a valley is experienced in the summer when the trees are in full leaf, the meandering river is at a low level and the various crops grown delineate the fields. If the same scene is viewed from the same position but this time in winter, the trees would have a different shape, having shed their leaves, the river may be in full spate disguising its natural course and the fields will have been harvested. It is necessary for the navigator to recognise that both representations are of the same objective location in space; otherwise they will be represented by different points in the cognitive representation. However, if at first this recognition does not take place, there must be some flexibility to allow for the two views or points to become one at some future time.

With sufficient experience of an environment, the navigator gets an impression that is functionally a survey level representation (Thorndyke & Hayes-Roth

1982). However this is not the same level of information as would be available from a cartographic map, which is implied in the term “cognitive map”. The navigator, when thinking about space is not passively scanning some mental image but is instead carrying out some action in the imagined environment. When planning a route, it is possible to mentally walk through buildings and obstructions in order to reach a given destination therefore the navigator can in fact imagine themselves to be at any point in the environment. They are not restricted to any single viewpoint and its resulting configurational representation.

Consistent with the notion of multiple possible viewpoints in the spatial representation, it has been suggested that a number of fixed systems of reference, which are relatively poorly integrated with each other, may be the norm for adults. For instance, Golledge (1978) suggested that we may accurately represent the metric relations (i.e. distance and direction) between a limited number of major reference points, and that these then become fixed points of reference for more local groupings at a lower hierarchical level. Thus we locate one of the minor landmarks by first orienting ourselves towards its nearest major reference landmark; from this we can then infer the route to the minor landmark. The relative orientations of the fixed systems are poorly specified and retain some subjective component, therefore Golledge suggests, it is problematic to infer relative location directly between minor points in different systems and it will therefore be necessary to go up and down the hierarchy.

3.13. Virtual Reality and Navigation

Computer simulated or virtual reality environments are now being used to study navigation. Acquisition of spatial knowledge for a VE has been shown to follow the same three stages as for a physical environment: landmark, route and survey knowledge. People develop a cognitive map for a VE in a similar manner to the way they do for a real-world environment (Ruddle, Payne and Jones, 1999).

Such environments are often non-immersive in that they are displayed on a monitor or fully immersive in that a head-mounted display is used which can produce an experience high in immersion and presence. There are limitations to the representation of virtual environments compared to a physically real space. A major limitation is the fact that the field of view is invariably narrower than would be available to a real world navigator and this has a large impact on the underestimation of distances, both in the real world and VE. A smaller field of view results in the compression of distance judgments. In other words, people tend to think things are closer than they actually are. It was hypothesised by Hagen (1978) that the reason for this is because people underestimate the unseen foreground distance between themselves and what they are actually viewing.

Further complications include poorer detail resolution, absence of vestibular or proprioceptive information and participants have to have experience of a mouse and/or joystick in order to direct movement (Maguire, Burgess and O'Keefe, 1999). Studies have shown that the construction of cognitive maps built during navigation of a virtual environment is comparable to those constructed in a real environment. Witmer, Bailey and Knerr, (1996) found that representations of

large-scale space learned in virtual environments could be transferred when the participant has to subsequently navigate in the real place. Ruddle, Payne and Jones, (1997) found that participants learned to navigate inside a simulated building as accurately as in the real building, whilst the addition of everyday objects as landmarks improved performance.

3.13.1. Neuroscience, Virtual Reality and Human Spatial Navigation

Tolman (1948) played a significant part in the study of navigation. He was best associated with his assertion that rats form cognitive maps of the spatial layout of their environment and do not learn the layout from simple stimulus-response connections. Tolman classed himself as a field theorist and believed that whilst learning the route around a maze, a rat constructs a "*field map*" of the environment. However, it was not until the 1970s that O'Keefe and Dostrovsky (1971) discovered place cells. These pyramidal cells, found in the rats hippocampus, have location-specific activity. Neuroscientist could therefore study the physiology of navigation.

Most research regarding navigation has been carried out on rats, birds and monkeys, however the results of such studies have been criticised in that they cannot necessarily be generalised to humans. In more recent years, this problem has been addressed in that, the neural basis of navigation in humans can be studied with the aid of PET and fMRI scans. Neuroimaging enables scientists to study the regions of the brain supporting navigation whilst the participant carries out navigational tasks. Results have found a pattern of activity associated with navigation. The key regions for navigation in humans include the medial and right inferior parietal cortex, the posterior cingulate cortex, parts of the basal

ganglia, the left prefrontal cortex, the bilateral medial temporal region and the hippocampus proper. There are some disagreements surrounding the role of the medial temporal region (Maguire, Burgess and O'Keefe, 1999). More specifically, the right temporal lobe, including the hippocampus and the hippocampal formation is important for the representation of space and specific place cells are active in the hippocampus when, in animal studies, the animal is in a particular location in its environment (O'Keefe and Dostrovsky, 1971). Other hippocampal neurons respond differentially to spatial stimuli irrespective of the spatial location of the animal (Rolls, 1996). Gron, Wunderlich, Spizer, Tomczak and Riepe (2000) suggest that these findings support the concept of a single world-centred (allocentric) representation of the environment residing mainly in the hippocampus (see fig 3.13).

They go on to explain that the posterior parietal cortex is involved in egocentric (body-centred) spatial cognition. Lesions in this structure significantly impair the formation of spatial representations of body locations with respect to the participants environment. Strong neural connections between the posterior parietal cortex and the hippocampal formation as well as the parahippocampal region suggest functional interactions between these structures during spatial-cognition tasks such as orienteering, navigating and forming visiospatial-memory traces. In addition to the hippocampus/parahippocampus areas and the parietal lobes, the right prefrontal areas are also activated by visiospatial working memory tasks and are implicated in complex navigation.

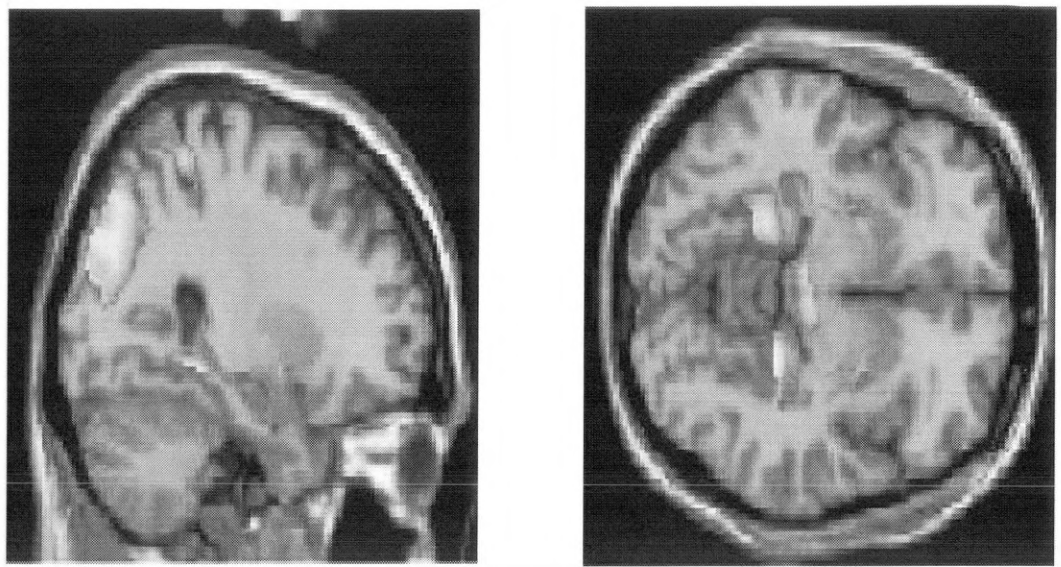


Fig 3.13. Gron et al (2000) found significant activation of the right hippocampus proper during a maze navigation test. The fMRI scan shows activity in the right hippocampal region in sagittal and transverse planes, other brain regions shown on the sagittal plane are the right medial occipital gyrus and two foci in the right parietal lobule. The superior colliculi as well as the left parahippocampal gyrus are shown on the transverse plane. (from Gron, Wunderlich, Spitzer, Tomczak and Riepe, 2000)

Navigation through mazes combined with functional neuroimaging, shows activation in the parahippocampus, medial parietal region and the posterior cingulate during the encoding phase. There is significant activity in the right parahippocampal gyrus when objects are used as specific landmarks for navigation but there is no activity in the hippocampus proper. Also, successful retrieval of previously well-learned routes to specific predefined goals activates the right hippocampal area, the more accurate the route taken to the target place the greater the activity in the right hippocampus.

3.13.2. Neuroscience, Navigation and Gender Differences.

Gron, Wunderlich, Spitzer, Tomczak and Riepe (2000) advised that females use the cerebral cortex, mostly the right parietal cortex, while males use the parietal cortex; they primarily use the left hippocampus which is a nucleus deep inside the brain which is not activated in the female brain during navigational tasks. Lesions of the entorhinal cortex cause greater impairment in males than females.

Studies on lesioned animals have shown that spatial cognition is also differently organised in male and female rats. In female rats, spatial tasks involve the phylogenetically newer neo-cortex, whereas males use the phylogenetically ancient subcortical nuclei. Performance of female rats in the Morris water maze is disrupted by frontal lesions to a significantly greater extent than in male rats as seen in figure 6.16 (Kolb and Cioe, 1996).

The Morris water task is used for measuring spatial navigation in mammals and was devised in response to the work of such researchers as O'Keefe regarding the neural basis of spatial and working memory. The task requires mammals, usually rats, to learn the topographical relationships among visible, distal cues in the room surrounding the pool in order to swim to a hidden goal platform located in a fixed position. The hidden platform means that the rat must find a position in space that it cannot hear, see or smell, in other words there are no local cues to guide its escape behaviour.

Morris showed that the ability to learn accurately in this task depended upon the integrity and plasticity of circuitry in the hippocampal formation and that rats with entorhinal cortex lesions suffer a spatial deficit as opposed to impairment induced

by motivational or sensorimotor factors (Morris, 1984). Morris goes on to make a distinction between learning by association and reward and learning by constructing a cognitive map. In the former case, he states that rats learn to navigate simple T-mazes by making simple binary decisions i.e. turn left or turn right. The correct decision leads the rat to a reward and its actions are therefore positively reinforced, placing no further demands upon the rats spatial localisation system. In the water maze, the rat has to constantly monitor its position in relation to extra-maze cues in order to attain accurate directionality indicating the use of a cognitive map.

Control and cortically lesioned rats continue to perform well on the task, swimming directly to the submerged platform. Rats that have suffered lesions to the hippocampus, however, behave as though naive to the task, swimming randomly around the water maze (see fig.3.14) However, when cued learning can be used, such as when obvious visual cues indicate the location of the platform, the performance of hippocampal lesion rats recovers with respect to the other experimental groups. This suggests that spatial memory is selectively impaired by hippocampal lesion and that other memory functions remain intact.

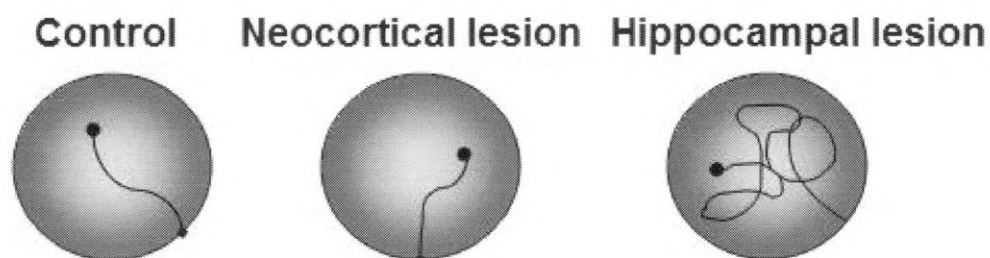


Fig. 3.14. Performances of control and lesioned rats in the Morris water task. (Morris, 1984)

3.13.3. Gender Differences In Navigating

Astur, Ortiz and Sutherland (1998) carried out a similar task to see if the task would generalise into the human domain and to see if sex differences exist in this area of topographical learning and memory. Astur *et al* used computerised 3D graphics to recreate the Morris Water Task and found that the task could be used with humans, revealing large sex differences in navigational performances favouring males. It was found that males swim for significantly shorter times to find the submerged platform. When the platform is removed, males spend significantly more of their swim time in the area of the pool where the platform had originally been placed and males were significantly more accurate in swimming towards the platform.

Dabbs, Chang, Strong and Milun (1999) measured navigation strategies and geographic knowledge in men and women. They found that males excelled at a Vandenburg and Kuse (1978) mental rotation task, which measures recognition of objects in rotated positions. They also found that males knew more about world geography and that males and females differed in navigation strategy, with males using miles and cardinal directions and females using landmarks and left right directions.

Gron, Wunderlich, Spitzer, Tomczak and Riepe (2000) carried out tests using such a version of the Virtual Morris Maze test whereby neural activity for each group of male and female participants was recorded. Although there was a great deal of overlap regarding the brain regions that were activated, they did however, find brain regions that were activated exclusively by either the male or female groups. Men showed activation in the left parahippocampal gyrus as well as the

left hippocampus proper, whereas, women showed activity of the left superior frontal gyrus and of the right medial frontal gyrus. Gron *et al*'s findings support the view that the hippocampus is involved in the processing of spatial arrangements that aid navigation and that the parahippocampal region is involved in processing of specific routes and places. This no doubt reflects the encoding of new places and topographic information.

Gron, Wunderlich, Spitzer, Tomczak and Riepe's (2000) paper goes on to explain that right parietal activity reflects the egocentric space representation frame that participants of the test constructed during navigation of the maze. Due to the first person view of the maze, parietal activity was generated during the translation of retinal coordinates to head centred or perhaps even body centred coordinates.

Midparietal precuneus activation is related to temporal order retrieval and is usually found in tests of episodic memory. Activation in this area, during the maze test, would be due to the functioning of working memory (implicit), whereby the data was recorded in order to keep track of the routes taken during navigation.

The bilateral lingual gyri are part of the occipitotemporal pathway that is used in object discrimination and recognition. The activity of this area during the maze test shows the recognition of landmarks or specific intersections that were coded in an object like manner.

They believe that behavioural gender differences in navigation performance are due to different neural substrates for spatial cognition. Women coped with the navigation test by using a right parietal and a right prefrontal area, whereas men used the left hippocampal region. This they suggest may be related to differences in the processing of spatial information. As women rely predominantly on landmark cues and males use both geometric and landmark cues (Sandstrom, Kauffman and Heuttel, 1998) activity in the prefrontal area in the female group reflects the demands of the working memory while holding landmark cues on-line and keeping track of the routes taken. For the males, left hippocampal activation represents the neural substrate that enables males to process multiple geometric cues. Male-specific hippocampal activity may also demonstrate the males reliance on the use of episodic memory information in navigation as the hippocampal formation functions in episodic memory.

3.14. Evolutionary Explanation Of Sex Differences In Navigation

The process of learning a new environment varies according to groups of people and different individuals. Such people may go through the steps in different ways or they may treat the environmental information differently. Females for instance are more inclined to give route descriptions typically using landmarks that can be seen or heard i.e. “make a left at the hardware store, carry on past the petrol station and when you pass the school take a right turn. At the end of the road you’ll see a house with bright blue shutters that looks like something out of a fairy tale, that’s the house you’re looking for.” Males tend to give an environment a configural description using abstract concepts such as North and South or absolute distance i.e. “Go south along High Street for 200 yards, turn left heading east

along Bell Street. At the intersection with Newton Road turn right, the house you are looking for is the fourth on the left.”

Age also alters the way in which environmental information is handled. Older people are less inclined to use configural knowledge and the landmarks they use consist of more personal and evaluative statements about scenes (Benyon, 2000).

It is crucial to this present research to understand why it is that males and females should differ when it comes to navigating. An important theory that has been put forward is the evolutionary theory.

3.14.1 Evolutionary Theory And Navigation.

There are many theories concerning the evolution of gender differences, one of them being the Hunter-Gatherer Theory (Eals and Silverman, 1994), which is based on the idea that selection for spatial dimorphism in humans was due to the sexual division of labour. Archaeological and Paleontological data show that across evolutionary times, males predominantly hunted and females predominantly gathered.

The success of a Pleistocene hunter depended on accurate large-scale navigation abilities, in that they had to be able to explore novel environments, keep track of orientation on long distance trips and be able to develop relevant representations of space i.e. directions and distances. The successful Pleistocene gatherer needed good small-scale spatial memory abilities such as learning the relative position of food plants in that they would have to be able to locate food plants within

complex arrays of vegetation and would also have to develop relevant representations of space i.e. relative positions.

According to the Hunter-Gatherer, males use Euclidean strategies, which are concerned with angles, distances and geometrical co-ordinates, due to their need to navigate for hunting, sometimes taking them vast distances from home. Females, on the other hand, used topological strategies, which refer to the presence and arrangement of certain features in the environment, for example landmarks, as they foraged for food and located and relocated seeds in their immediate surroundings therefore needing to take in detailed information. There has been a great deal of research into the use of these opposing strategies and Galea and Kimura (1993) and Miller and Santoni (1986) found supporting evidence for the use of these strategies.

Galea and Kimura's study investigated the differences between males and females and their strategies used in route learning. They also had a control for visual item memory. All participants (48 females, 49 males) were instructed to learn a route on a map and were asked to recall the route and the landmarks that were on that route. Males made fewer errors and took fewer trials to reach the criterion. It was also found that females remembered more landmarks both on and off the route. Males performed better than females in their knowledge of the Euclidean properties of the map.

Miller and Santoni looked at the sex differences in the nature and accuracy of schematic cognitive maps. In the first experiment 11 and 19 year olds examined

schematic maps and gave directions from their memory between locations on the map. It was found that males throughout the ages used more Euclidean strategies in their directions and were more accurate. In the second experiment adults were given the schematic task and a differential aptitude test of spatial ability, for both measures sex differences were found.

Eal and Silverman's study looked at spatial strategies using unusual objects. They found that females were more successful than males in recalling common objects across incidental and directed learning conditions. The same occurred in the recall of unusual objects in the incidental learning condition however not in the directed condition. Their research also found that females are better than males at keeping track of objects and finding objects that are lost. Further, after viewing a set of objects once and then viewing it again with some of the objects moved, females identified more objects that had been moved than males.

Males however know more about far off regions of the world can locate more countries on a world map and perform better in the annual National Geography Bee (Liben 1995).

Dabbs, Chang, Strong and Milun (1998) suggest that object location memory promotes the use of landmarks in navigation, whereas three-dimensional visualisation promotes the use of abstract Euclidian navigation. It is also plausible, they say, that the landmarks are more important in local navigation than in knowing where countries and regions are located.

Dabbs *et al* described the navigational techniques of an experienced hunter, stating that they follow wandering paths in seeking game. Information regarding potential landmarks is processed but is in fact subsequently discarded. Therefore, much of the detail that they pass on their search for game is ignored. On their route home, the hunter will not retrace their route but will instead take the quickest and most direct path. To do this successfully, the hunter must know where he is and what direction to head in, in order to get home. Maintaining a birds eye view of their position is more advantageous to the hunter than being able to recall paths and landmarks.

To conclude, Silver and Eals evolutionary perspective holds that a prehistoric division of labour supported differing reproductive needs of men and women. Females who could better keep track of relationships, activities, objects, locations, and landmarks near home were more successful at acquiring resources needed to bear and raise offspring. Males who could travel in unfamiliar territory, estimate distance, and navigate using a birds eye orientation were more successful at competing with other males, finding mates, and fathering offspring. In this view, neither sex has superior spatial skills. Men and women have different skills, suitable to handling different aspects of the environment most important to their own sex.

Astur, Ortiz and Sutherland (1998) suggest that the large sex differences found in spatial abilities may be due to a variety of factors as reviewed by Maccoby and Jacklin (1974) in their book on the psychology of sex differences. Astur *et al* also points out that social pressure may make a difference in that males often have

more experience concerning navigation and spatial performance and that evolutionary and hormonal factors have to be considered regarding spatial performance. These very factors will be discussed in depth in the next two chapters.

3.15. Summary

Vision is our most dominant sense and most of our information about the world is derived from light that enters the eyes with the brain processing the information in such a way as to allow us to navigate a three-dimensional environment. We are able to recognise objects and to judge depth by reconstructing three-dimensional images from the two-dimensional pattern of light that falls on our eyes. This is possible due to stereopsis and monocular cues and it is perspective and shading that are of particular importance to the 3D mental rotation tests used in this present study.

Navigational awareness was defined as having a complete navigational knowledge of an environment in which people use common-sense knowledge of geographic space. It was explained that there are two main types of spatial knowledge that are required when people engage in spatial learning, procedural and configural knowledge. The first step towards constructing a complete spatial representation requires the navigator to at first discriminate landmark information from the environment; it is then possible to learn route formations or pathways from one landmark to the next. Route knowledge is ego-referenced and normally the navigator will gain such knowledge by exploring the environment personally. Route knowledge therefore refers to the spatio-temporal relations between specific environmental features.

The final step is survey or configural knowledge that refers to map like structures that include information about the inter-relationships among locations. Knowledge is reached when the navigator is aware of the spatial relationship between landmarks and includes Euclidian measurements that are cardinal directions and metric distances which serve as coordinates to map spatial relationships among distinctive locations within a network of routes. It is generally accepted that humans have the potential to acquire a mental representation of their environment or a “cognitive map” and a number of theories have been put forward to explain how such a structure is developed during the learning process. Two major theories concerning the way adults construct mental representations of space over time were discussed, the first by Siegal and White’s sequential and hierarchical model, and the second termed “*the information processing account*”.

It was not until the 1970s that neuroimaging could be used to study the areas of the brain that support navigation and O’Keefe and Dostrovsky (1971) discovered place cells in the rats hippocampus which have location-specific activity. The key regions of the brain used for navigation in humans have now been mapped particularly the role of the hippocampus that is important for the representation of space. Of importance to this present study is the finding that there are sex differences regarding brain activation during navigating tasks. It was found that although there is a great deal of overlap regarding the brain regions that were activated, there were brain regions that were activated exclusively by either the male or female groups. Men showed activation in the left parahippocampal gyrus

as well as the left hippocampus proper, whereas, women showed activity of the left superior frontal gyrus and of the right medial frontal gyrus.

It is thought that behavioural sex differences in navigation performance are due to different neural substrates for spatial cognition. One explanation for these sex differences is Silverman and Eals evolutionary perspective that is based on the idea that selection for spatial dimorphism in humans was due to the sexual division of labour. This view claims that neither sex has superior spatial skills but that males and females have different skills, suitable to handling different aspects of the environment most important to their own sex. In chapter four differences between the males and females with regards to spatial ability will be discussed in detail.

An understanding of the differences are crucial to this present study for if the differences in navigation and spatial ability are purely biological or innate then reliance on the development of interfaces sympathetic to females will be necessary to aid females with their interaction with VRs and VEs. If the differences are environmental or cultural, it will be necessary to find ways to overcome poor spatial skills through experience or other environmental factors that will be discussed in the second half of chapter four.

Chapter Four

Nature or Nurture

Introduction:

This chapter will examine the biological and environmental differences between males and females, primarily focusing on differences in performance with regards to spatial skills and abilities. The first half of this chapter will discuss the biological approach to sex differences by first considering the evolutionary theory pertaining to those behaviours related to the development of spatial and navigational abilities. A short review of cognitive differences will be followed by a discussion of behavioural differences with regards to navigation, which are reflected in differing patterns of brain activation. The hormonal approach to differences in behaviour will refer to effects on brain function with special reference to studies on patients with Congenital Adrenal Hyperplasia (CAH). The last section will discuss brain lateralisation whereby research with brain impaired patients have shown that generally, the left hemisphere is used for speech while the right hemisphere is used for perception and spatial functions.

The second half of this chapter deals with some of the environmental factors that effect behaviour and in particular, spatial skills. Reference will be made to the consideration that females have lacked experiences needed for developing spatial skills. Attention will be paid to computer game play and interface proficiency as researchers believe computer games are the doorway to computer literacy and that females are not encouraged to play games due, in part, to there content and negative stereotypical gender roles. Of particular importance to this research will be the sections concerning self-perception, motivation and practice, all of which

are environmental factors that have a direct effect on performance. All three factors will be manipulated, in phase two of the experimental chapters, in order to see if there is an effect on spatial performance in the mental rotation tests.

Self-perception is greatly influenced by parents, teachers and society as a whole with stereotyping often contributing towards negative self-perception that in turn may lead to damaging behavioural consequences. It will be argued that the negative portrayal of females in the majority of computer games is one reason girls and women are not as interested in computer games as males. Lack of interest means lack of spatial skill development and lack of practice with computer technology and interface proficiency.

Spatial skills are vital for navigation within VR and mental rotation is vital for both performance on MRTs and navigation. Spatial and mental rotation skills can be improved through practice and it is the intention of this present study to test participants on mental rotation performance before and after practice to see if gender differences, favouring males, can be decreased or eliminated. It will be argued, once again, that practice with computer games can improve spatial skills as well as preparing children for the digital world and computer literacy

Mental rotation and navigational ability are innate and the sex differences between males and females have left females at a biological disadvantage. As computer literacy is a vital contributor to educational and professional success in the 21st century it is important to ascertain whether or not environmental factors such as practice, self-perception and motivation can be manipulated in such a way as to

improve the skills needed to balance that which nature has seen fit to knock asunder.

Nature

4.1 Sex Differences

One of the most influential books in psychology of the 70s was Maccoby and Jacklin's (1974) "*The Psychology Of Sex Differences*". Their book was a review of gender differences in which they described a pattern of gender related cognitive strengths and aptitudes. The consensus of opinion pointed to females having greater verbal and fine motor aptitude; they excel at quantitative tasks such as arithmetic calculations, perceptual speed and the production and comprehension of complex prose. Males, however, generally have greater spatial/quantitative aptitude, especially in areas concerning cognitive tasks that require transformations in visual spatial working memory. Males are also better at spatio-temporal responding, motor skills involved in aiming, and fluid reasoning in abstract mathematical and scientific domains such as problem solving, mathematics, the ability to locate an object in space and mentally rearranging objects etc. Proposed reasons for these differences have ranged from hormonal and social factors to differing hemispheric maturation rates. It is important to understand the possible reasons and explanations for such differences as ultimately the reason for the differences may well indicate whether or not the poor performance by females within Virtual Reality, with regards to spatial ability and skills, can be rectified or remedied.

4.2 Evolution Theories And Spatial Dimorphism.

There are many theories concerning the evolution of sex differences, one of them being the Hunter-Gatherer Theory (Eals and Silverman, 1994), which is based on the idea that selection for spatial dimorphism in humans was due to the sexual division of labour. This evolutionary theory was briefly discussed in chapter three but a fuller explanation will give a clearer understanding of the differences between males and females and how they may have come about.

Historically it has been accepted that males and females behave differently due to some innate factors such as aggression, dominance and even the way the sexes differ in problem solving. Darwin wrote about natural selection, whereby the environment in which an organism existed “selected” traits necessary for survival particularly to reproductive age and hence transmitted to any offspring. In the case of humans, not only did sex differences in reproductive roles emerge but also differences in activities, these differences are referred to as the division of labour. In other words, the environment in which our earliest ancestors existed may have selected different abilities for males and for females. Major abilities selected for males/hunters are accurate targeting and, relevant to this present study, long distance navigation. A number of studies involving route learning have found that females tend to use landmarks such as buildings or natural features as referents, whilst males tend to use distance or cardinal directions. (Ward, Newcombe and Overton, 1986, Eal and Silverman’s 1994, Galea and Kimura, 1993). The finding from such studies is that males generally have better map knowledge and navigational skills than females.

Navigational ability and skill requires the individual to have the ability to recognise a scene from various orientations and to develop cognitive maps and it is this very ability that is necessary for imaginal rotation such as demonstrated in the Shepard and Metzler (1971) Mental Rotation Tests. Females/gatherers, however, according to Eal and Silverman's (1994) hunter-gatherer theory, are generally better at recalling the positions of objects in an array. Their evolutionary inheritance is such that at one time the ability to detect small changes in the home environment would have contributed to survival i.e. recognising if an intruder or predator had entered the home or identifying berries in an array of bushes and trees. The female ability to use landmarks when navigating may have been because females did not traverse great distances from the home therefore only needing to use fixed landmarks as locator signs.

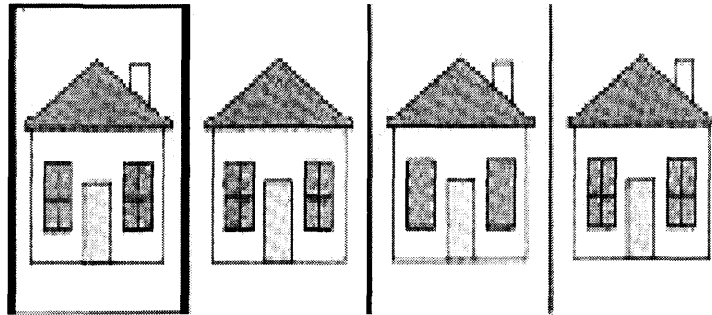
According to Geary (1998), human beings are designed to attempt to control social, biological and physical resources that support their survival and reproduction. Sexual selection, therefore, is related to differences in the physical, social and psychological development of boys and girls. One important function of development is having a period of immaturity whereby the growing child faces new experiences, building on their innate cognitive abilities, and developing behavioural and social skills, which will be needed in adulthood.

Archaeologists and Palaeontologists believe that across evolutionary times, males predominantly hunted and females predominantly gathered food for survival. The success of a Pleistocene hunter depended on accurate large-scale navigation abilities, in that they had to be able to explore novel environments, keep track of

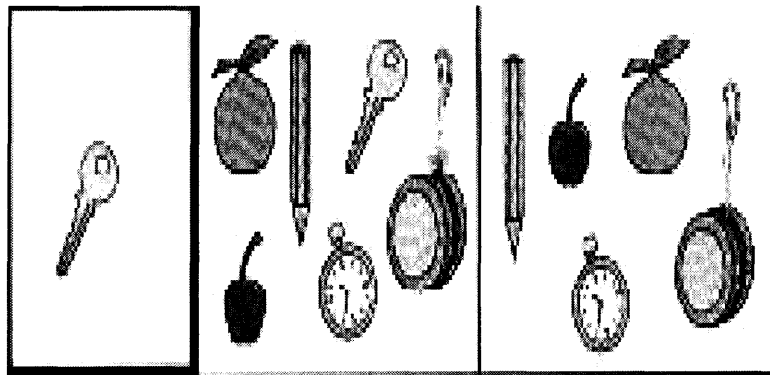
orientation on long distance trips and be able to develop relevant representations of space i.e. directions and distances. The successful Pleistocene gatherer needed good small-scale spatial memory abilities such as learning the relative position of food plants in that they would have to be able to locate food within complex arrays of vegetation and would also have to develop relevant representations of space i.e. relative positions. According to the Hunter-Gatherer theory, males use Euclidean strategies, which are concerned with angles, distances and geometrical co-ordinates, due to their need to navigate for hunting, sometimes taking them vast distances from home. Females, on the other hand, used topological strategies, which refer to the presence and arrangement of certain features in the environment, for example landmarks, as they foraged for food and located and relocated seeds in their immediate surroundings therefore needing to take in detailed information. There has been a great deal of research into the use of these opposing strategies and Galea and Kimura (1993) and Miller and Santoni (1986) found supporting evidence for the use of these strategies. In their tests of route learning and the accuracy of schematic cognitive maps males made fewer errors, took fewer trials to reach the criterion and used Euclidean strategies in their directions. It was also found that females remembered more landmarks both on and off the route. Males performed better than females in their knowledge of the Euclidean properties of the map.

4.3 Sex Differences

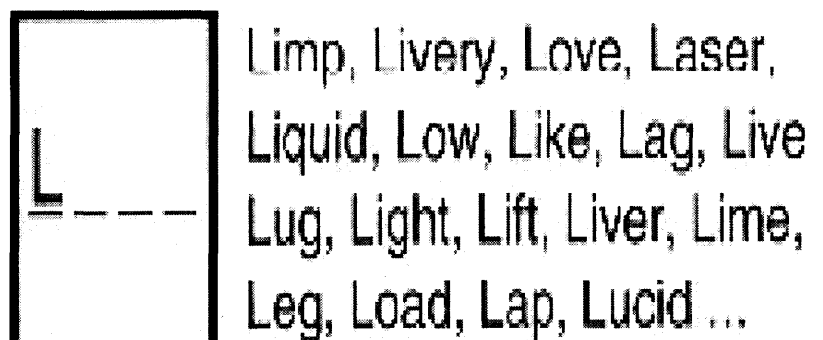
With regards to this present study, it is necessary to understand the differences between males and females with regards to their cognitive and primarily spatial abilities.



Females tend to perform better on tests of perceptual speed in which subjects must rapidly identify matching items for example, pairing the house on the left with its twin.

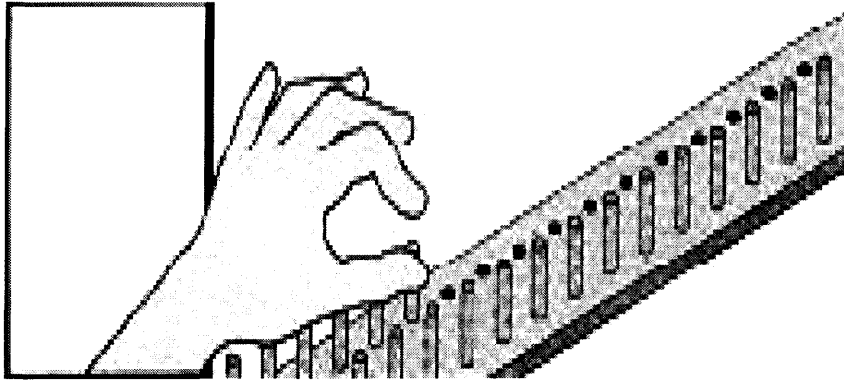


Females are better at remembering whether an object, or a series of objects, has been displaced:

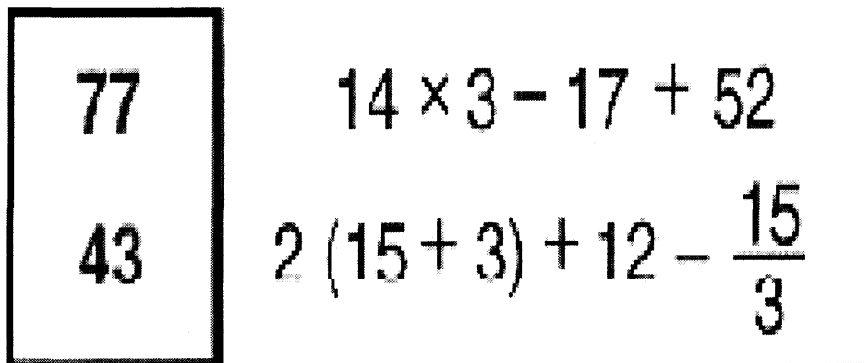


On some tests of ideational fluency, for example, those in which subjects must list objects that are the same colour, and on tests of verbal fluency, in which

participants must list words that begin with the same letter, females also outperform males.

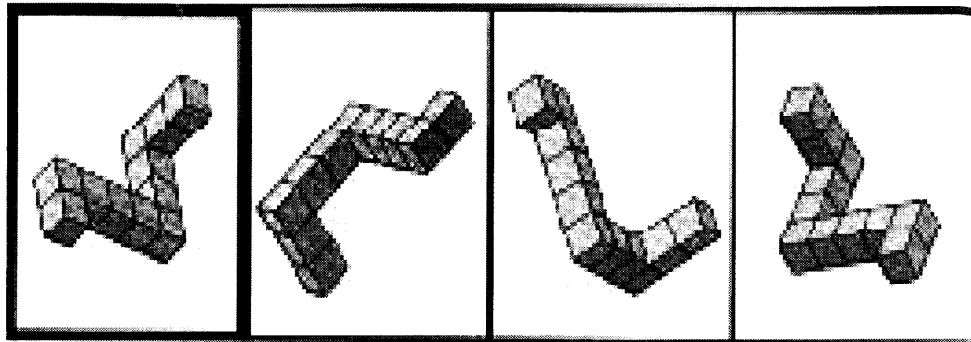


Females do better on precision manual tasks, that is, those involving fine motor co-ordination, such as placing pegs in holes on a board.

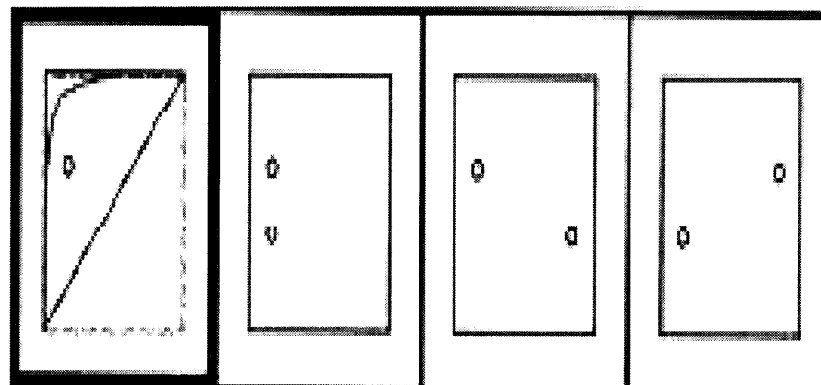


And females do better than males on mathematical calculation tests.

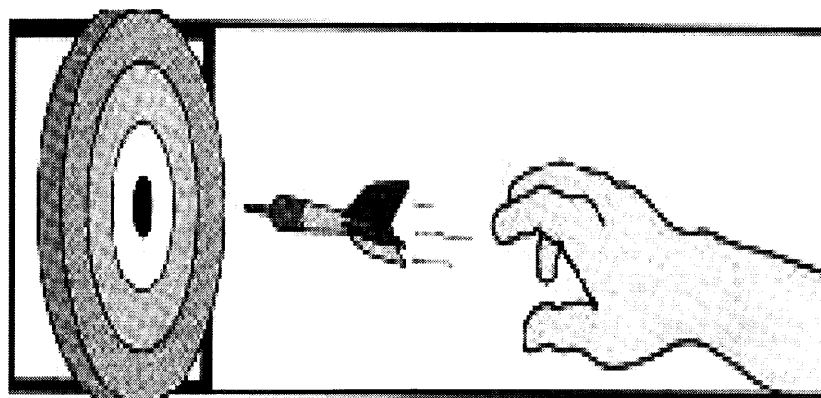
Males, however, generally have greater spatial/quantitative aptitude, especially in areas concerning cognitive tasks that require transformations in visual spatial working memory, spatio-temporal responding, motor skills involved in aiming, fluid reasoning in abstract mathematical and scientific domains such as problem solving and mathematics.



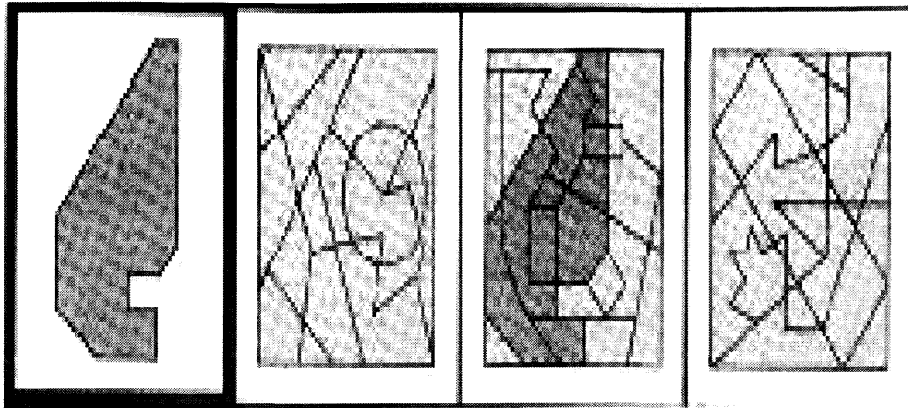
Males tend to perform better than females on certain spatial tasks. They do well on tests that involve mentally locating and rotating an object or manipulating it in some fashion, such as imagining turning three-dimensional objects



or determining where the holes punched in a folded piece of paper will fall when the paper is unfolded.



Males are more accurate than women in target-directed motor skills, such as guiding or intercepting projectiles:



Males do better on disembedding tests, in which they have to find a simple shape, such as the one on the left, once it is hidden within a more complex figure:

1,100	<p>If only 60 percent of seedlings will survive, how many must be planted to obtain 660 trees?</p>
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(Drawings after Kimura, 1992)

Males also tend to do better than females on tests of mathematical reasoning:

Reasons for these differences have ranged from hormonal and social factors to differing hemispheric maturation rates. For every explanation there is a contradiction, however, it is important for this study to make a clear differentiation between what is genetic (nature) and what is learned from the environment (nurture)

4.4 The Biological Approach

Recent research regarding the biological approach to navigational differences is that carried out by Riepe, Groen, Wunderlich, Spitzer and Tomczak, (2000). Neuroscientists have now shown that these behavioural differences are reflected in differing patterns of brain activation during navigation. Not only are there differences in performance between males and females, but they also try to solve the same problem with different parts of the brain. Riepe *et al* used functional magnetic resonance imaging (fMRI) technology to study the brains of males and females as they tried to find their way out of a complex 3-D virtual reality maze presented on a computer screen. The males escaped from the maze in an average of 2 minutes and 22 seconds whereas it took the females an average of 3 minutes and 16 seconds. Looking for an exit to the VR maze activated many of the same brain regions in both males and females, including the right hippocampus (see figure 4.1).

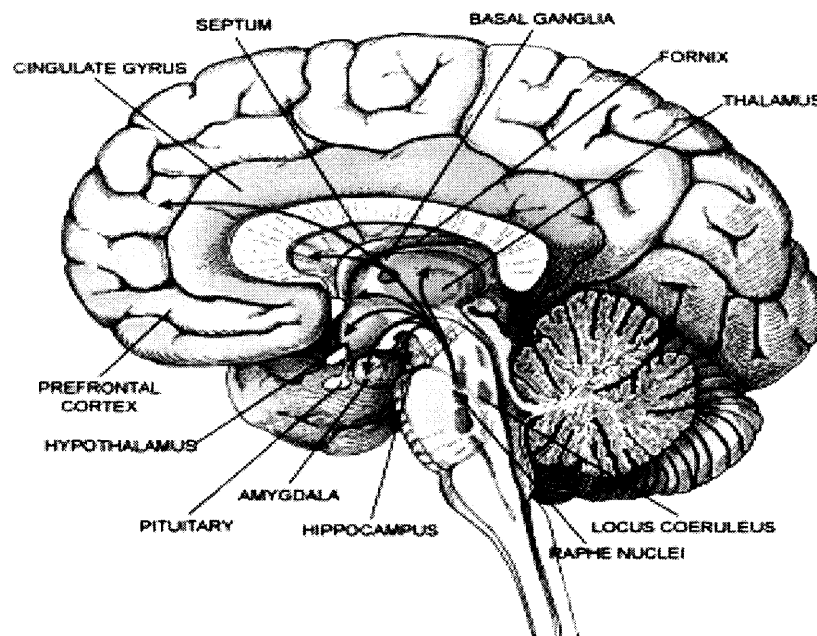


Fig. 4.1 shows a cross section of the human brain, including the hypothalamus, the area of the brain that organises female and male reproductive behaviours.

The hippocampus is a small structure deep in the brain that is critical for learning and memory it also helps us to “picture” the surrounding environment so that we can navigate it. In addition, however, the males brains coped with the task by also using the left hippocampus in order to process geometric information. The females in the study did not activate the left hippocampus but did use the right parietal cortex (on the side of the head roughly above the ear) and the prefrontal cortex (directly behind the forehead). This distinct functional anatomy of spatial cognition in females versus males may be related to differences in the processing of spatial information.

The parietal region appears to be involved in telling us where we are situated in the environment. Riepe *et al* believe the parietal region also helps females record data about landmarks in the maze. The prefrontal cortex is thought to be the seat of working memory. Activity of the prefrontal area among females may reflect working memorys efforts to keep those landmark cues "online" and available for navigation therefore supporting prior work that suggested that females rely mostly on landmarks to navigate while males lean toward using geometry, the hippocampus activity in the males might be needed for the geometric approach.

The study confirmed in humans behavioural differences that have been reported in laboratory rats. A male rat with a damaged hippocampus is much more impaired at finding his way than a similarly damaged female, suggesting that females are getting help with navigation from other parts of the brain. Riepe *et al* conceded that, while his fMRI studies confirmed that men and women each use a distinct suite of brain parts for navigation, they leave open the question of whether those

differences are hard-wired from birth or are the result of experience. However, Riepe *et al's* study is one of the first to show a clear relationship between brain activation and behavioural performance and indicates that males and females use different cognitive strategies to solve navigation tasks.

4.5 The Hormonal Approach:

Doreen Kimura (1992) studies the neural and hormonal basis of human intellectual function and her research involves studying sex differences in the brain, paying particular attention to the effects of hormones on brain function. Kimura advised that males and females differ not only in physical attributes and reproductive function but also in the way in which they solve intellectual problems. Importantly for this study, she stated that it has been fashionable to insist that these differences are minimal, the consequence of variations in experience during development, however Kimura points to the fact that the bulk of evidence suggests that the effects of sex hormones on brain organisation occur so early in life that from the start the environment is acting on differently wired brains in girls and boys. Such differences make it almost impossible to evaluate the effects of experience independent of physiological predisposition.

Behavioural, neurological and endocrinologic studies have made it easier to understand the processes giving rise to sex differences in the brain. Studies of the effects of hormones on brain function throughout life suggest that the evolutionary pressures directing differences allows for a degree of flexibility in cognitive ability between the sexes. With the exception of the sex chromosomes, males and females share genetic material therefore it is important to know how

such differences come about. Differing patterns of ability between males and females most probably reflect different hormonal influences on their developing brains. Early in life the action of estrogens and androgens (male hormones chief of which is testosterone) establishes sexual differentiation. In mammals, including humans, the organism has the potential to be male or female. If a Y chromosome is present, testes or male gonads form. This development is the critical first step toward becoming a male.

If the gonads do not produce male hormones or if for some reason the hormones cannot act on the tissue, the default form of the organism is female. Once testes are formed, they produce two substances that bring about the development of a male. Testosterone causes masculinisation by promoting the male, or Wolffian, set of ducts and, indirectly through conversion to dihydrotestosterone, the external appearance of the scrotum and penis. The Mullerian regression factor causes the female, Mullerian, set of ducts to regress. If something goes wrong at any stage of the process, the individual may be incompletely masculinised. Not only do sex hormones achieve the transformation of the genitals into organs, but they also organise corresponding male behaviours early in life.

4.5.1 Hormonal Influence On Behaviour

Studies using rodents by Goy (1989) found that there is a tendency to develop female behaviours when there is an absence of masculinising hormonal influence. If a rodent with functional male genitals is deprived of androgens immediately after birth, either because they have been castrated or have been administered with a compound that blocks androgens, male sexual behaviour, such as

mounting, would be reduced. Instead female sexual behaviour, such as lordosis (arching of the back), will be enhanced in adulthood. Similarly, if androgens are administered to a female directly after birth, she displays more male sexual behaviour and less female behaviour in adulthood.

In the rat, two processes of defeminisation and masculinisation require somewhat different biochemical changes. Testosterone can be converted to either oestrogen that is usually considered to be a female hormone or dihydrotestosterone. Defeminisation takes place primarily after birth in rats and is mediated by oestrogen, whereas masculinisation involves both dihydrotestosterone and oestrogen and occurs for the most part before birth rather than after. A substance called alpha-fetoprotein may protect female brains from the masculinising effects of their oestrogens. The area in the brain that organises female and male reproductive behaviour is the hypothalamus (see fig 4.1). Gorski, Ahmed, Shryne and Branch (1991) have found that a region of the pre-optic area of the hypothalamus is visibly larger in male rats than in females. The size increment in males is promoted by the presence of androgens in the immediate postnatal, and to some extent prenatal, period.

The sexual behaviour of a rat and how it can be altered via the influence of hormones is important to the understanding of sex differences in spatial ability in humans. As Kimura (1999) pointed out, evolutionary explanations for the differences that exist between males and females depended on natural selection, whereby the environment selected those traits of individuals that are likely to enhance survival. Traits that allowed an individual to survive until able to reproduce are also traits that were transmitted to the offspring. When considering

sex differences in behaviour, this explanation accounts for differences in reproductive roles as well as for differences in activities as reflected in the division of labour explained earlier.

A study by Simon LeVay (1991) reported that one of the brain regions that is usually larger in human males than in females, an interstitial nucleus of the anterior hypothalamus called the INAH3, is smaller in homosexual than in heterosexual men. LeVay pointed out that this finding supported suggestions that sexual preference has a biological substrate. (However, there has been much debate concerning this study and a critique by Tahir can be viewed on line at <http://salmon.psy.plym.ac.uk/year3/tahir.html>) Further studies by Allen and Gorski (1992) of the anterior commissure (AC) found similar results; in this case homosexual men and women (all presumed heterosexual) had a larger AC than heterosexual men. These findings are important to this study as homosexual and heterosexual men may also perform differently on cognitive tests. Homosexual men perform less well on several spatial tasks than do heterosexual men. Heterosexual females and homosexual females attained similar scores on all cognitive variables, except the water jar test whereby the homosexual females were poorer than the heterosexual females.

In a study carried out by Hall and Kimura (1995), they found that homosexual men had lower scores on targeting tasks than did heterosexual men. On the other hand, lesbians tended to throw more accurately than heterosexual females. They suggest that the study shows an association between sexual orientation and motor performance. As with cognitive tasks, the motor performance profile of

homosexuals is made up from some male typical and some female typical abilities indicating that sexual orientation and motor/cognitive pre-dispositions have early biological contributions.

The lifelong effects of early exposure to sex hormones are characterised as organisational because they appear to alter brain function permanently during what is termed a critical period. Administering the same hormones at a later stage has no such effect. The hormonal effects are not limited to sexual or reproductive behaviours. Behaviours such as problem solving, aggression and even the tendency for rough and tumble games appear to be controlled by such hormonal effects (Meaney, 1998). These behaviours are known to be ones in which males and females differ.

Interestingly, as Hall and Kimura (1995) reported, hormonal manipulation during the critical period can alter these behaviours. Depriving newborn male rats of testosterone by castrating them or administering oestrogen to newborn female rats resulted in a reversal of sex-typed behaviours in the adult animals. Treated females behaved like males, and treated males behaved like females. It is possible that natural selection for reproductive advantage could account for the evolution of such navigational differences. Sherry, Jacobs and Gaulin (1992), suggested that in some species of voles in which a male mates with several females rather than with just one, the range he has to cover is greater. The ability to navigate successfully would then be critical for reproductive success. They advised that the hippocampus plays an important role in spatial memory and spatial cognition and that natural selection and sexual selection have resulted in an increase in the

size of the hippocampus in a diverse group of animals that rely on spatial abilities to solve problems.

Gaulin, FitzGerald and Wartell (1990) supported Sherry *et al's* findings as they too found sex differences in laboratory maze learning only in voles that were polygamous such as the meadow vole, but not in monogamous species, such as the prairie vole. The hippocampus, they stated is larger in male polygamous voles than in females. Results such as these may indicate that behavioural differences may parallel structural ones.

4.6 Congenital Adrenal Hyperplasia (CAH).

Evidence of the influence of sex hormones on adult behaviour is less direct in humans than in other animals. An important source of evidence comes from studies of girls exposed to excess androgens in the prenatal or neonatal stage. The production of abnormally large quantities of adrenal androgens can occur because of a genetic defect called congenital adrenal hyperplasia (CAH). CAH is a disease that affects the manufacture of the stress hormone cortisol; girls with classic CAH are born with masculine appearing external genitals but with female internal sex organs. Boys with classical CAH look normal at birth, so their diagnosis of CAH is sometimes missed.

Studies by Ehrhardt (1975) found that girls with excess exposure to androgens mature to be more tomboyish and aggressive than their unaffected sisters. Observations made by Berenbaum and Hines (1992) found that girls unaffected by CAH played with dolls, kitchen supplies, books and board games, two and a half times longer than girls affected by CAH. These girls played with boys' toys,

such as cars and lorries and construction toys, two and a half times longer than unaffected girls. There is no reason to believe that the parents of CAH girls would not encourage feminine preferences in their CAH daughters whilst encouraging it in an unaffected daughter, therefore, these findings suggest that the toy preferences were actually altered in some way by the early hormonal environment.

Important to this present study and the distinction between environmental and genetic factors is that spatial abilities that are typically better in males are also enhanced in CAH girls. Resnick and Berenbaum (1986) reported that affected girls were superior to their unaffected sisters in a spatial manipulation test, which included two spatial rotation tests and a disembedding test. Generally there is a male advantage to all of these tests. There was no difference between the two groups on other perceptual or verbal tasks or on a reasoning task.

Studies such as these suggest that the higher the androgen levels, the better the spatial performance but this does not necessarily seem to be the case. Shute, Pellegrino, Hubert and Reynolds (1983), suggested that the relationship between levels of androgens and some spatial abilities might be non-linear. In other words, spatial ability might not increase as the amount of androgen increases. Shute *et al* measured the levels of androgens in blood taken from male and female participants and divided each into high and low androgen groups. Their participants fell within the normal range for each sex, bearing in mind that androgens are present in females but in very low levels. Surprisingly she found that females with high androgen levels, were better at the spatial tests, however, in

males the reverse was true. Low androgen men performed better than those with high levels of androgens.

Gouchie and Kimura (1991) conducted a study along similar lines by measuring testosterone in saliva. Their results supported Shute *et al's* in that the optimal testosterone level again appears to be in the low to normal range with low-testosterone men being superior to high-testosterone men, but high-testosterone women were better than low-testosterone women. Such findings suggest some optimum level of testosterone for maximal spatial ability. This level may fall in the low male range. On their mathematical reasoning tests however, the results were similar to those of spatial ability tests for men, low-androgen men tested higher. In women, however, they found no relationship with maths scores.

These findings are consistent with suggestions made by Benbow (1988). She proposed high mathematical ability has a significant biological determinant. Benbow reported consistent sex differences in mathematical reasoning ability favouring males. These differences were most pronounced at the upper end of the distribution, where males outnumber females 13 to one. Benbow argued that these differences could not be entirely explained by socialisation.

4.7 Brain Lateralisation

Another approach to probing differences between the male and female brain is to examine and compare the functions of particular brain systems. A particularly non-invasive way to do this is to study people who have experienced damage to a particular area of the brain. Studies of this kind have shown that the left half of the

brain in most people is primarily used for speech whereas the right is used for certain perceptual and spatial functions.

It is widely assumed by many researchers studying sex differences that the two hemispheres are more asymmetrically organised for speech and spatial functions in males than in females and parts of the Corpus Callosum, which is a major neural system connecting the two hemispheres, may be more extensive in females. Techniques that look at brain asymmetry in normal-functioning people sometimes show smaller asymmetries in women than in men. Damage to one brain hemisphere sometimes has a lesser effect in women than when compared to a male having an injury in a similar location. De Lacoste and Holloway (1982) reported that the back part of the Corpus Callosum, an area called the Splenium, was larger in women than in men. This finding has subsequently been both denied and confirmed and a fuller explanation is given in a review by Driesen and Raz (1995). However, Allen and Gorski (1991) found the same sex-related size difference in the Splenium. The interest in the Corpus Callosum arises from the assumption that the larger the Callosum or commissural area, the more nerve fibres that connect the two hemispheres. If females do have more connecting fibres then the implication would be that their hemispheres have superior communication.

Although sex hormones can alter Calomel size in rats, it is unclear whether the actual number of fibres differs between the sexes. Sex difference, in cognitive function, has yet to be related to a difference in callosal size, however, the view that a male brain is functionally more asymmetric than a female brain is long-

standing. Geschwind and Galaburda (1985) proposed that testicular androgens increased the growth of the right hemisphere relative to the left thereby increasing the functional potency of the right hemisphere.

Diamond, Dowling and Johnson (1981) found that for the right cortex, the outer layer of the brain is thicker than the left in male rats but not in females. This asymmetry is also caused by androgens. De Lacoste, Horvath and Woodward (1991) pinpointed early hormonal influences on this asymmetry with regards to the human foetus in that androgens appear to suppress left cortex growth. They found the right cortex was thicker than the left in males indicating that there may be some anatomic reasons for believing that the two hemispheres might not be equally asymmetric in males and females.

Research by Frederikse, Lu, Aylward, Barta and Pearson (1999), investigated sex based asymmetries of the inferior parietal lobule (IPL). The males showed significantly larger left, but not right, IPL volume when compared to the females, they also showed a leftward asymmetry for the IPL, with a less marked opposite asymmetry in females. Frederikse *et al* concluded that such sexual dimorphism might possibly underlie the cognitive differences observed between the sexes. Lesions of the inferior parietal cortex in humans produce a consistent and readily recognised set of clinical signs and symptoms, which include deficits in visual-spatial perception, spatial memories, route-following and oculomotor control (Critchley, 1953; Lynch, 1980).

Kimura also studied the overall differences in spatial ability between males and females to see if they were related to differing right hemispheric dependence for such functions, damage, she said, to the right hemisphere should be worse for males with regards to spatial performance. Kimura administered mental rotation tests in order to investigate the ability of patients with damage to one hemisphere of the brain.

Patients with damage to the right hemisphere scored lower scores for both sexes on the tests than patients with damage to the left hemisphere. Females were generally poorer than the males on the block spatial rotation test. Concerning damage to the right hemisphere, there was no greater effect in males than in females. These results suggested that the normal differences encountered between males and females on such rotational tests are not the result of differential dependence on the right hemisphere. Some other brain systems had to be mediating the higher performance by men.

It is not known exactly to what extent the differentiation of the central nervous system is determined by biological factors as compared to the influences of early external input. As Newcombe (1982) stated,

“although differential lateralisation patterns cause cognitive differences, cognitive differences could also cause lateralisation patterns: this can be called the strategy issue...[another] possibility is that another variable (such a sex-differentiated experience) could also cause both lateralisation and cognitive differences independently of each other.”(P.232.)

Without going into this area of research any further than necessary it may be concluded that sex differences in asymmetry varies with the particular function being studied and that it is not always the same sex that is more asymmetric. Taken altogether, the evidence suggests that the male and female brain is organised along different lines from very early in life and that during development it is the sex hormones that direct such differentiation.

4.8 Hormonal Fluctuations

Hampson, Rover and Altmann (1988) have shown that cognitive patterns may remain sensitive to hormonal fluctuations throughout life. They were able to show that the performance of females on certain tasks changed throughout the menstrual cycle as levels of oestrogen increased or decreased. High levels of oestrogen were associated with relatively poorer spatial ability and enhanced articulatory and motor capability. Seasonal fluctuations in spatial ability in men have also been observed in that their performance is improved in the spring when testosterone levels are lower.

4.9 Conclusion To Sex Differences

As a final word in this section, it must be stressed that the differences described above must be seen in context, as some are slight whereas others are quite large. Males and females overlap enormously on many cognitive tests that show average sex differences and researchers use variations within each group as a tool to gauge the differences between the groups. As a way of explaining, on one test the average score is 105 for females and 100 for males. If the scores for females ranged from 100 to 110 and for males from 95 to 105, the difference would be more impressive than if the females scores ranged from 50 to 150 and the males

from 45 to 145. In the latter case, the overlap in scores would be much greater. One measure of the variation of scores within a group is the standard deviation. To compare the magnitude of a sex difference across several distinct tasks, the difference between groups is divided by the standard deviation. The resulting number is called the effect size. Effect sizes below 0.5 are generally considered small. Based on Kimura's data (1999), there are typically no differences between the sexes on tests of vocabulary (effect size 0.02), non-verbal reasoning (0.03) and verbal reasoning (0.17). On tests in which subjects match pictures, find words that begin with similar letters or show ideational fluency such as naming objects that are white or red, the effect sizes are somewhat larger: 0.25, 0.22 and 0.38, respectively. As mentioned above, females tend to outperform males on these tasks. Researchers have reported the largest effect sizes for certain tests measuring spatial rotation (effect size 0.7) and targeting accuracy (0.75). The large effect size in these tests means there are many more men at the high end of the score distribution.

Nurture

4.10 The Environmental Approach to Gender Differences

This approach states that the importance of experience cannot be separated from the biological attributes of the different genders. An example of experience and how it can alter the brain structure was recently studied by Maguire (2002) who looked at the brains of London taxi drivers and found that their brains had an unusually large development in the hippocampus the area of the brain used for navigation, memory and learning.

Taxi drivers are required to pass a series of vigorous and demanding navigation tests in order to obtain their licenses. The brains of 16 male taxi drivers were compared to the brains of a control group of 50 men of similar age. As stated earlier, the back of the hippocampus, in the taxi drivers, was larger than the comparison group. The back of the hippocampus is associated with spatial memory. Although the overall size of the brain was normal, the drivers' hippocampus adapted to help store the detailed mental map of the city. Maguire explained that her findings indicated that exercising that part of the brain heavily could lead to changes in its size. Evidence for this is found in the fact that the men who had been cab drivers for 40 years had a larger hippocampus than those still considered novices. While the left posterior hippocampus was larger on average in cabbies than other adults, its size did not increase with the number of years spent driving, suggesting that its role in spatial navigation differs from that of the right side.

4.11 Nature and Nurture

Whether the Hunter-Gatherer Theory is correct or not, evidence is such that a biological distinction cannot be denied. However, in addition to such biological "mean" differences, there may be other factors influencing or even boosting this pre-existing sex difference. With regards to VR, a lack of practice and therefore poorer performances may be more due to motivational factors, which in turn may be directly linked to the biological differences between males and females. Robert Reuter suggested (personal correspondence)

“that females lack practice specifically in the VR environment, because computer games are male, not only in terms of spatial aspects but also in terms of brute aggressiveness...especially in terms of the hunter motivational aspect.”

He explained that males love to hunt, shoot, run and hide, etc. whether it is a necessary evolutionary aspect of the Pleistocene Age or the natural “instincts” of a modern day three-year-old boy. It is therefore scientifically sound to assume that precisely those things, which were adaptive for male humans, still influences the way the male brain is organised. The way the brain is organised will therefore influence the learning behaviours that a male will favour and indeed excel at.

Concerning the realm of differences in spatial cognition, Reuter believes several factors (cultural and biological) work in conjunction. From very early in their development, boys are better explorers of their spatial environment, on average they play further away from their houses, they like to play “hunt'n'kill” more than females, even although there are many females who have a more boyish profile. Such “boyish” and “girlish” behaviours have been recognised "by culture" as male and female behaviour and "culture", i.e. education and parenting, reinforces gender-typed behaviour. It is therefore impossible to disentangle culture and biology.

Gender differences in play behaviours regarding navigational and environmental strategies develop at around eight years of age. Boys play, more frequently than girls, games that involve gross locomotor activity, such as running. This difference has been found in both industrial and pre-industrial societies (Eibl-

Eibesfeldt, 1989). Boys are three times more inclined to take part in group level, competitive play, such as football than are girls. This results in gender differences in gross locomotor activities, which in turn create neuromuscular changes. Males, therefore, are more adapted for running and traveling long distances on foot, having larger play ranges than do girls. Within these play ranges boys take part in locomotor activities such as football but they also explore and manipulate their environment much more than girls (Matthews, 1992). The gender difference in the size of the play range and the types of exploratory games that boys indulge in, are related to the development of certain spatial competencies. Matthews (1986, 1987) found that boys maps of their home area were more detailed, accurate and more extended in dimension, involving a higher degree of complexity than that of girls of a similar age. Hart (1979) pointed out the importance of experience for environmental development as his studies showed a high correlation between the accuracy and extent of childrens maps with the limit of their home range activities.

It is of course possible that the difference in play range is due to parental restrictions. Parents may prevent their daughters from playing too far from home, which indicates an environmental influence on gender differences, however, such gender differences are found in societies where there are no such restrictions (Matthews 1992). Girls are more cautious than boys with respect to exploring territory that is unfamiliar to them. (Sherry and Hampson, 1997)

4.12 The Feminist approach

Relevant to this present study are the results of meta-analysis. The Feminist psychology perspective often denies the existence of differences and justifies their

claims by laying the blame at faulty research practice (Caplan, Macpherson and Tobin 1985). Recently, a review of research papers (MacIntyre 1997) found that with regards to spatial ability (also mathematical and verbal abilities), most of these differences have either disappeared or are negligible. Social and feminist psychologists therefore feel that they were justified in saying that social effects augment and interact with whatever constitutional differences may have been present from the start. Intellectual aptitudes may be originally based on built in constitutional factors, but that this is greatly magnified by social expectations and stereotypes. However, as mentioned in previous chapters, one of the most interesting and persistent gender influenced cognitive abilities involves mental rotation. A paper and pencil version of the Shepard and Metzler (1971) Mental Rotation Test has consistently been shown to produce one of the largest and most reliable gender differences, favouring males, in the cognitive literature although the effect size has reduced from 0.77 in 1978 to 0.38 in 1987. Mental rotation tests will play a significant part in the experimental sections of this study.

It has to be emphasised that if feminist psychologists are correct, in that cognitive differences have diminished, then the differences in performance in VR, as outlined in chapter one, may have explanations other than biological. It is therefore important to understand the environmental influences that may shape behaviour and performance particularly with reference to navigation and mental rotation abilities.

4.13 Socialisation and Education

The environmental approach looks at the impact of socialisation. According to research by Hensel (1989) girls are encouraged, throughout their years at school,

to be passive, caring, to take no risks, and to defer to male voices during debates and public discussions. They are also given the strong impression that mathematics is for boys. Such early influences have an impact on how girls both learn and behave in school.

Throughout childhood, children are often unconsciously encouraged by their parents, siblings, teachers etc. to adopt gender-stereotyped roles. Boys are encouraged to play with action toys and therefore learn about mathematical concepts. Young girls are encouraged to communicate, learning how to be verbally expressive. Their toys and games give them little opportunity to experience mathematical concepts such as velocity, angles, or three-dimensional configurations that ultimately form the core of mathematics.

Hensel explained that while boys learn language and discourse skills they also learn to be comfortable with a physical world, and to be able to translate that physical world into the discourse of the mathematics class. For boys, mathematics is not just an abstract concept, it is a firm part of their experiential base, and they can visualise maths processes. For instance, young boys can create a three-dimensional object "in their heads." while young girls often need to try to construct this knowledge without a base in reality; it therefore seems to have no relevance to their own experiences. Girls try to create a process they cannot "see" by using words rather than mental pictures, using the skill they have developed.

Kramarae and Treichler (1990) have studied the differential styles of interacting in a classroom situation and suggest that the way girls are encouraged to interact and

communicate does not fit into the standard strategies used to teach mathematics. The traditional classroom format, where there is a non-personal, hierarchical, classroom interaction, which favours the male discourse model, is defined as the way in which knowledge is constructed and exchanged in classrooms.

Kramarae *et al* advise that a curriculum that fails to engage girls, unconscious behaviour patterns and expectations, outright hostility to girls by their teachers and male students, or the lack of encouragement from guidance counsellors, are all part of the process that actively discourages females from entering into or remaining in, the world of mathematics. The importance of what actually happens in classrooms, particularly in terms of teacher-student interactions and both teacher and student expectations should not be underestimated. It is within the classroom that gender role expectations and socialisation converge to influence both the curriculum and the real experiences of the students.

Gilligan (1982) and Belenky. (1986) suggested that females most commonly use a "connectivist" mode of thinking, therefore the traditional mode of mathematics education, devoid of human context, is both alien and alienating. Their research revealed that the image of mathematics is cold, cut-and-dried and impersonal. These reasons are often put forward by females to explain their dislike of mathematics, and consequently, of their decision to abandon mathematics from the outset.

Research may also point to disparities in the math curriculum itself that reinforces the perceptions that girls are not mathematical. Early elementary math curriculum

focuses on interactive, memorisation skills that girls have a natural ability for. The focus, however, later shifts to the higher order, abstract concepts that depend on spatial visualisation, which is considered a male skill. While girls are achieving in early elementary school, they are using skills developed from an innate ability and the discourse focused on "remediation" for boys, in other words, helping them to develop these initial skills. When the curriculum shifts, however, there is no parallel discourse shift to include girls in the development of their higher order math skills. Boys have grounding in this discourse and so it often continues on without the involvement of girls, an uninvolvement that remains unnoticed by teachers and students themselves.

To further complicate the issue Irvine (1985) refers to the considerable amount of research that indicates patterns of gender role stereotypes. Teachers see girls as objects of attachment rather than of concern; they perceive girls more favourably, because they are not attracting attention. In pre-school settings, teachers initiate more contact with boys, and boys are more likely to call out answers. Teachers have also been found to respond significantly less to girls attempts to initiate conversation. In this pattern of control of discourse, it is not even necessary for males to have the right answers, but rather to get noticed and engage with the teacher. Sadker and Sadker (1985) indicated that at all grade levels and in all subjects, females have fewer opportunities to interact. Unfortunately they also found that the educators were unaware of the impact of this pattern of bias.

There is little doubt that this discourse mode, all is it unconscious, reinforces a girls' sense of disengagement from mathematics and removes them from the

construction of higher level cognitive skills needed for progressing in mathematics. Those girls who do attempt to adopt a male discourse model are often penalised for taking part in what is considered to be a male domain. According to Pearson (1987) a male can be perceived as ambitious, assertive and independent whereas if a female should display such behaviours, she is labelled as being aggressive, pushy and argumentative. The social messages therefore are that technology, mathematics, science and even gym are male domains and because girls feel less confident they tend not to select such subjects at school. Campbell (1986) found that the lack of confidence girls' have in their maths ability, their perception of their own achievement within a difficult subject and their view of maths being a male subject, all have an impact on a girls' attitudes, achievements and participation in advanced courses. Tartre and Fennema (1991) findings were similar to Campbell's and added that when looking at single sex schools, where girls did not view mathematics as being exclusively male, they tend to achieve higher maths results.

In another study that explored the dominant and submissive gender role behaviours in pre-school children and their teachers, the patterns of male domination of conversation emerged, a pattern modelled by the adults (Hendrick and Strange, 1989). The pre-school teachers interrupted less when the boys were talking and they made no attempt to balance the larger number of male interruptions by encouraging girls to speak up or by recommending the boys allow the girls speaking time. As the researchers pointed out, the pre-school girls were learning to know their place and what traditionally constitutes socially acceptable gender-role behaviour. Girls were learning to assume a less aggressive social role

in conversation. It is quite possible since what they had to say was treated with less respect, they were also learning they were less important in the social scheme of things than were their male counterparts.

In more recent years, as an example of socialisation, researchers such as Feingold (1988) have suggested that in certain countries, cognitive differences such as spatial ability have declined over the last few decades due to a change in socialisation influences. As the difference in the male and female environment has become less divided then cognitive differences, as would be expected, have declined. Feingold argues that the reason that sex differences, favouring males, in maths aptitude has been decreasing is because boys and girls are being treated more alike in the school environment and therefore this is reflected in performance.

4.14 In the home

It cannot be assumed that girls' are born hard-wired to dislike mathematics but environmental influences from an early age can greatly shape their beliefs and attitudes. Within the home environment the treatment of male and female infants remains fairly stereotypical. For instance, girl babies are handled more delicately than are boys (Braun & Linder, 1989). Even the toys given to boy and girl babies differ; from birth girl infants are discouraged from risk-taking, from exploring the world around them. Boys are given toys that encourage small motor skills and spatial visualisation, necessary for later maths success. Girls' toys often encourage relational or traditionally nurturing activities.

In child care settings, with infants and children between 13 months and two years, research shows that child care providers respond to the children based on their own gender role beliefs, and they use the child's gender to guide their responses (Fagot, Hagan, Leinbach and Kronsberg, 1985). While there was no sex difference in the number of attempts infants made to communicate with the adults, the infant behaviours to which adults responded differed significantly. Adults were more likely to respond when girls used gestures or gentle touches or talked, and when boys forced attention through physical means or cried, whined, or screamed. When children are older and their behaviours more clearly defined, teachers abandon the gender stereotype and begin to respond to the specific behaviour of the child, but by this point the unconscious assignment of gender role stereotypes to the child is no longer necessary. For the most part, by the time they are three, children are performing well-rehearsed communicative activities that were developed before the child had an effective language system.

According to Peretti and Sydney (1984) toys are associated with a child's expression, fantasy, exploration, construction, education, cognitive development and gender role learning. In their study they assessed the influence of parental toy choice stereotyping on child toy preference and gender role typing among nursery school children. Their results showed that child toy preference was significantly related to parental toy preference, which in turn, was associated with gender role typing. Thus we make attributions based on the child's perceived gender, and have expectations, which the child reflects. Social learning theory would therefore suggest that a child is rewarded for gender specific behaviours and therefore regards itself as belonging to that gender.

4.15 Environmental Influences That May Affect Performance

In this present study three environmental influences, namely motivation, practice and self-perception will be used in order to manipulate performance on MRTs. Sex differences are usually given to explain why it is that males generally outperform females however, should it be found that the above mentioned environmental influences can be used to increase performance levels, then these findings will be important for training purposes with regards to mental rotation, navigation and ultimately performance within VR. It is therefore necessary to look at each in more detail:

4.15.1 Motivation

What cannot be assumed when studying performance is that the participants in tests are all alert and optimally motivated. Neither can it be assumed that the experimenters test is the most important thing the participant has to do that day. Individual differences in cognitive ability are known to exist and can be controlled for in testing situations, however motivational states are often ignored. How we perform on certain tasks will greatly depend on how much we are motivated to carry them out. There are many theoretical perspectives that are used to try and explain individuals' beliefs, values, motivations and goals. Researchers are interested in finding out why these factors relate to achievement behaviours.

Motivations are forces acting either on or within a person to initiate behaviour therefore the study of motivation is the study of action. Modern theories of motivation focus primarily on the relation of beliefs, values and goals with action. Eccles (2002) gave a comprehensive overview of the many motivational theories

on offer that come under the heading of expectancy-value models of behaviour. Expectancies being the beliefs we have about how we will perform on different tasks or activities, some of these theories are now considered:

4.15.2. The Self-Efficacy Theory

The self-efficacy theory, as proposed by Bandura (1997) defines self-efficacy as an individuals' confidence in their ability to organise and carry out a particular course of actions in order to solve a problem or to accomplish a task. He believed that some people have a strong sense of self-efficacy while others do not. Some believe they can produce the required results even on the most difficult tasks whilst others believe they can only be effective on easier tasks.

Bandura's theory therefore focuses on expectancies for success, but makes two distinctions. The first being outcome expectations which are beliefs that certain behaviours will lead to certain outcomes i.e. practising will improve performance. The second is efficacy expectations, which are the beliefs about whether or not one can effectively perform the type of behaviours that are necessary to produce a particular outcome i.e. believing that practising sufficiently hard will reach proficiency. Bandura emphasised that these two expectancy beliefs are very different because an individual can believe certain behaviours will produce a certain outcome (outcome expectation) but they may not believe that they themselves can perform that behaviour (efficacy expectation). It is the individuals' efficacy expectations that are the major determinant of goal setting, activity choice, willingness to expend effort and persistence. Bandura (1997, 2002)) stated that high personal academic expectations predict subsequent performance, course enrolment, occupational choice and aspirations.

4.15.3 The Behavioural Theory

An individual has to be motivated in order to pay attention while learning, however, anxiety can decrease the motivation to learn. Using conditioning the likelihood of an action being repeated is increased therefore behavioural theories of learning tend to focus on *extrinsic* motivation such as rewards while cognitive theories deal with *intrinsic* motivation such as goals. In Tolman's (1932) theory of purposive behaviourism, primary drives create internal states (i.e., wants or needs) that serve as secondary drives and represent intrinsic motivation. According to Tolman, a new stimulus becomes associated with already meaningful stimuli through a series of pairings; thereby making redundant any need for reinforcement in order to establish learning. It has to be pointed out that much of Tolman's research was carried out with rats in the context of place learning.

Tolman's main principles for learning are:

1. Learning is always purposive and goal-directed.
2. Learning often involves the use of environmental factors to achieve a goal (e.g., means-ends-analysis)
3. Organisms will select the shortest or easiest path to achieve a goal.

4.15.4. The Cognitive Theory

In cognitive theory, one well-developed area of research, which is highly relevant to learning, is achievement motivation (Atkinson & Raynor, 1974). Motivation to achieve is a function of the individuals desire for success, the expectancy of success, and the incentives provided. Studies show that, in general, people prefer tasks of intermediate difficulty. In addition, students with a high need to achieve

obtain better grades in courses that they perceive as highly relevant to their career goals.

Eveland (1998) used a general theory of information processing to explain influences on learning such as motives and goals, the level of attention paid to content and the degree to which content is processed in a deep or elaborative manner. He stated that learning is accomplished through the processing of information such as devoting attention to a stimulus or elaborating on it using past experience or existing knowledge, which in turn is controlled by motivations or goals.

Broadbent (1958) refers to two dimensions of personality that have a great effect on variations in motivation and performance. These dimensions of personality are introversion-extraversion and stability-neuroticism. Extraversion was associated with decrements in performance over time whereas neuroticism was associated with greater decrements following stress.

4.15.5. The Humanistic Theory

On the other hand, according to Carl Rogers (1969) all individuals have a drive to self-actualise and this motivates learning. Rogers distinguished two types of learning: cognitive (meaningless) and experiential (significant). The former corresponds to academic knowledge such as learning vocabulary or multiplication tables and the latter refers to applied knowledge such as learning about engines in order to repair a car. The key to the distinction is that experiential learning addresses the needs and wants of the learner. Rogers listed the qualities of

experiential learning as being personal involvement, self-initiated, evaluated by the learner, and having pervasive effects on the learner.

The main principles of Roger's theory are:

1. Significant learning takes place when the subject matter is relevant to the personal interests of the student
2. Learning which is threatening to the self e.g., new attitudes or perspective are more easily assimilated when external threats are at a minimum
3. Learning proceeds faster when the threat to the self is low.
4. Self-initiated learning is the most lasting and pervasive.

4.15.6. Development Of Student Motivation

When it comes to theories of learning, motivation has a primary role. Motivation is closely related to arousal, attention, anxiety and reinforcement. A student, and indeed a participant in a psychology test, who is intrinsically motivated undertakes a task for its own sake, for the enjoyment it provides, the learning it permits or the feeling of accomplishment it evokes. An extrinsically motivated student performs in order to obtain some sort of reward or in order to avoid some punishment external to the activity itself, such as getting good grades, stickers, teacher approval (Lepper 1988) or indeed financial rewards.

Motivation to learn, according to Brophy (1987), is a competence that is acquired through general experience and stimulated through modelling, communication of expectations and direct instruction or socialisation by significant others i.e. parents and teachers. Home environment is crucial to a child's attitude towards

learning, failure and exploration and will depend on whether or not their natural curiosity is encouraged.

Once a child starts school, they form beliefs about their school-related successes and failures. The sources to which children attribute their success, such as effort, ability, luck, or level of task difficulty, and their failures, such as lack of ability or lack of effort, will have major implications regarding the approach they will use regarding learning situations. Wong (2002) stated that student' perceptions of positive relationships with parents and teachers contribute to success in academic settings. High achievement and motivation is linked to interpersonal variables such as parent attachment, parent involvement and teacher autonomy support. There are also intra-personal variables such as perceived competence, perceived control and perceived autonomy support to be considered.

4.15.7. Extrinsic or Intrinsic Motivation

The difference between intrinsic and extrinsic motivation is crucial to learning and performance. Lepper (1988) stated that intrinsically motivated students use strategies that demand more effort, enabling them to process information more deeply. When students tackle complex intellectual tasks, those with an intrinsic orientation tend to use more logical information gathering and decision making strategies than those students who are more extrinsically orientated.

It has been found that in the world of sports, women are less competitive than men and are motivated to participate by intrinsic, participating in sport for satisfaction, rather than extrinsic, participating in sport for rewards, motivations. The best

sports performers with regards to medal winning were those with high levels of extrinsic motivation (Chantel, Debreva-Martinova and Vallerand 1996) however, it was those with high levels of intrinsic motivation that ensured continuing attendance and adherence to their chosen sport (Gould, Feltz and Weiss, 1985). Gould *et al* also found that females tended to take part in sports more for the social aspect than competition, ranking friendship and fun as important.

In this present study, motivation will be manipulated in that a “prize” of one hundred pounds will be given to the participant who is the fastest and most accurate on an MRT. Extrinsic motivation is therefore being used to encourage optimal performance.

4.16. Practice And Training

According to Lohman, and Nichols (1990), improvement on spatial skills is, to a great extent, task specific, meaning that with any given individual, large improvements on one spatial task does not necessarily mean that all spatial abilities have improved significantly. They state that those individuals who have had little practice performing spatial tasks will have the greatest benefit from training with regards to their spatial cognitive skills. Practice on a variety of tasks would encourage generalisation, with the greatest changes coming from experiences that allow for a gradual increase of a richer knowledge base rather than training in particular skills.

The extent to which spatial skills can be trained is important, as practice effects have been found in research into spatial abilities. Saccuzzo, Craig, Johnson and

Larson (1996) for instance found that both males and females improved when given practice on computer-based spatial tests. Initially the males were significantly better than females but after practice, the females improved at a significantly higher rate than the males, ultimately leveling their performances on the test. Baenninger and Newcombe (1989) account for this result by suggesting that females have more room for improvement in their spatial skills whereas males were already operating closer to their maximum potential.

4.16.1. The Effect Of Training

A study by Turos and Ervin (2003) investigated the effectiveness of training for male and female students on a mental rotation test. The laboratory-trained group was given mental rotation tests four times, one week apart. The self training group went to the lab in week one and four but were requested to log into the lab site in weeks two and three for self training and the no training group received mental rotation tests in week one and four. They found that between sessions one and four there was a significant difference in performance in all groups. Males were significantly more accurate at session four than the females suggesting that more than four training trials were needed in order to close the gender gap that was initially found in trial one, favouring males. This did not apply to reaction time; males and females had equal improvement between trial one and four. Only females in the lab and self-training groups improved significantly with regards to accuracy. This may be due to males having reached a ceiling in their ability to improve whilst the females had greater scope for improvement.

A study by Vasta, Knott and Gaze (1996) successfully eliminated gender differences in Piaget's water-level task by training males and females in advance with a session that gave them information about the task and feedback on practice trials. Vasta found that females who had the training did slightly better on the task than their male colleagues who had also had the training. When asked to explain the principle behind the task, many more men than women, in both the training and control group, answered correctly. More women in the training group answered the water-level task correctly, than did women in the control group. Vasta believes that success on this task depends not on direct knowledge of the task but on the ability to deduce the correct answer from accumulated knowledge about water, gravity and physics. This ability to deduce from bits of useful information may account, he says, to the difference in performances between males and females.

Lawton and Morrin (1999) used a similar strategy to Vasta when helping females with their performance on a real world mental rotation task. The participants had to move about in a 3-D video world consisting of hallways at right angles to each other. The participants could make two, four or six turns and then point towards the direction from which they started. Males performed better overall on all trials with males averaging 20 degrees closer to the correct answer. They added that by accounting for video-game experience, the difference between genders decreased. This they said pointed to the significant role of the environment in gender differences. Their training had taken less than an hour but this was not enough to compensate for years of unequal environmental exposure.

Baenniger and Newcombe (1987) used a real world navigation task along with training techniques to eliminate gender differences. They took 120 students to an unfamiliar campus and one by one, took them on a tour of new building. Having reached a room in the basement, the participant was asked to point in the direction of building that had been pointed out to them before they had entered the building. Males outperformed the females, however, if the participants had been warned to keep the position of the building in mind during the tour, the females performed as well as the males, thus indicating that the type of instruction is important to spatial tasks. Baenninger stated that her study showed that there was no underlying biological inability for women to do this task.

Baenninger also carried out studies with children showing the effects of spatial training on girls' ability to carry out standard measures of spatial ability. They found that, with fifth graders, if the training was sex-typed for girls in that the children had to draw quilt patterns, the girls' performance improved but not the boys' and that if the training was sex typed for boys then the boys improved but not the girls. These findings show that various spatial skills can be learned through experience and training.

4.16.2. Computer Experience:

Murphy (2001) wrote that video games are the technological equivalent to giving a child a "headstart", especially for boys, which the games market currently targets. Computer based games prepare children for their participation in the digital world. Games can lead children into computer literacy via enjoyable interaction instead of formal classroom training. Many games help to improve

cognitive skills including the maintenance of attention and orienting objects in space. Murphy suggested that this type of learning incorporates both individual and interpersonal motivations. Intrinsic motivation is found in the way of challenge and self-confidence. Again, in the world of computing, girls rate themselves significantly lower than boys on computer ability. Boys, however, show higher levels of confidence and a more positive attitude about computers than do girls with boys entering the classroom with more prior experience in the use of computers and games (Admin, 2001).

McClurg and Chaille (1987) found that certain games enhanced the development of spatial ability. They found that both boys and girls benefited from practice but it had to be taken into consideration that males use computers and play video games more often than females. However, when girls play computer games that facilitate spatial ability, the effects are as great as when boys play the same games. The effects on spatial cognition and practice with regards to improvements in performance must be viewed as task specific.

Research by Subrahmanyam and Greenfield (1996) also suggested that spatial skills are related to video game playing. Marble Madness for example improved spatial performance with regards to anticipating targets and extrapolating spatial paths. They described spatial skills and iconic representation as being crucial to most video and computer games as well as many computer applications. Skills in using two-dimensional representations of hypothetical space are central to many computer applications such as programming and games. These skills are

necessary for reading and using the information on computer screens. Okagaki and Frensch (1996) found similar results with regards to the game Tetris.

4.16.3. Motivation, Computer Games and V.R.

Malone (1981) presented a theoretical framework for intrinsic motivation in the context of designing computer games for instruction. Malone argued that intrinsic motivation is created by three qualities: challenge, fantasy, and curiosity. Challenge depends upon activities that involve uncertain outcomes due to variable levels, hidden information or randomness. Fantasy should depend upon skills required for the instruction. Curiosity can be aroused when learners believe their knowledge structures are incomplete or inconsistent. According to Malone, intrinsically motivating activities provide learners with a broad range of challenge, concrete feedback, and clear-cut criteria for performance.

VR is used more and more in education and training as it is able to supplement the users ability to visualise. Importantly however, is the systems ability to develop the users independent thinking and increasing the extent to which they learn and retain specific knowledge. Also desirable is the systems ability to increase the users motivation for learning (Mills and De Araujo, 1999). Byrne (1993) stated that the experiential quality of learning through VR, in other words, the feeling of presence and interaction, encourages users to use the VR system to build their own knowledge worlds and that in turn, becomes a vehicle for learning. Motivation is important to learning and Constructivists believe that an exploratory method of learning maintains and possibly increases motivation. Needless to say, a motivated student learns more easily than a non-motivated student, therefore, if

the software can increase motivation this in turn will enhance the learning of the student.

4.16.4. Gender Differences In Computer Game Play.

The Internet, computer software and computer games are typically targeted at traditional male interests such as action-related sports, games and computer programming. It is little wonder that males have greater experience with regards to computer technology. A study by Subrahmanyam, Greenfield, Kraut and Gross (2001) cited the CEO of Lucas Learning as admitting that their products were designed exclusively for boys. Subrahmanyam and Greenfield (1998) found that girls like games that contain features that can be identified in their day to day play and reading tastes. Girls pretend play is based on reality, and involves characters that are either familiar or are at least realistic (Tizard, Philips and Plewis, (1976). Boys pretend play, on the other hand tends to be based on fantasy. If the manufacturers of computers games do not produce games that are suitable or motivating for females then girls will not receive the experiences required for developing spatial skills. Boys, with their biological and environmental advantages will continue to dominate in male orientated domains such as maths, architecture, engineering etc.

VR used for educational and training purposes must use the knowledge gained by the games companies when in the design process. The differences in game play should be reflected in the strategies used for teaching important information to students, recruits or employees. Relevant content will increase motivation to learn, reducing negative self-perception and therefore increasing performance.

4.17. Stereotyping and Self-Perception.

According to Taylor, Neter and Wayment (1995) self-perceptions are an integral part of our lives and self-evaluation is fundamental component of self-regulation.

They stated that:

“Without feedback on where one stands and how one is doing with respect to ones goals, effective self-regulation is virtually impossible.” (Pg 1278.)

Unfortunately individuals are far from being accurate self-evaluators. Beyer (1998) stated that outside evaluators are better assessors of an individuals' performance than the individual themselves. Beyer gave Risucci, Tortolani and Ward's (1989) findings as an example in that while peer and supervisor ratings of surgical residents' performance correlated between .66 and .86, self-ratings of performance did not correlate with either peer or supervisor assessments. These findings therefore show that there is a disagreement between self-views and external criteria.

4.17.1. Gender Differences in Self-Evaluation.

Gender is one variable that affects the accuracy of an individuals' self-perception. For example, Beyer (1990; Beyer and Bowden, (1977) compared participants' post task self-evaluations of performance to their actual performance. They found that females' self-evaluations were inaccurately low compared to their performance on masculine tasks. Males either overestimated or accurately estimated their performance. However, in tests considered to be feminine, no gender differences in the accuracy of self-evaluation were found.

Beyer explained her results in terms of self-consistent tendencies; pre-task expectancies of performance influences post-task self-evaluations of performance. In her 1998 paper she emphasised that females are not inaccurately negative self-evaluators in general but instead these difficulties are limited to masculine domains and she cited Hannover (1991) whose findings showed that females but not males underestimated their grades in mathematics that is considered to be a male domain. With regards to German, a female domain, no gender difference in the accuracy of self-evaluation was found.

The consequences of inaccurate self-perception, in respect of this present research, are that inaccurately negative self-evaluations may have damaging behavioural consequences. Perceptions of competence, or lack of, are tied to aspirations, preference for challenging tasks, curiosity, intrinsic motivation, persistence and task performance (Beyer, 1995; Elliott and Dweck, 1988; Cutrona, Cole, Colanero, Assouline and Russell, 1994). This therefore means that should participants in the mental rotation tests hold negative self-perceptions regarding their competence, this will be reflected in their performance.

In a navigation test, Kozlowski and Bryant (1977) found negative interrelations between subjects' self-estimated spatial anxiety (worry about becoming lost) and their sense of direction and pointing accuracy. Higher ratings of spatial anxiety in females have also been found by Bryant (1982) and Lawton (1994), as has stronger feelings of disorientation (La Grone, 1969). Lawton's study found that spatial anxiety correlated negatively with the use of an orientation strategy, more favoured by males, and with performance in mental rotation and self-perception

tasks, where males performed better than females. High spatial anxiety predicted a higher proportion of landmarks in the representation of environmental knowledge of females (Schmitz, 1997)

Stereotype Threat Theory explains that being outnumbered in a social situation may cause females to suffer from stereotype threat (Aronson and Steele, 1995). An experience of stereotype threat could potentially interfere with intellectual performance, particularly when individuals are highly identified by society as possessing superior achievement in the given domain. This was demonstrated by Brown and Josephs (1999) when they showed that high achieving females performed significantly worse than males on maths ability when the stereotype about female maths ability was made more salient. This finding is relevant to explaining sex differences as individuals may under-perform from a loss of motivation due to stereotype threat. In this present study self-perception will be manipulated in a similar way to see if Stereotype threat has an effect on MRT performance.

4.17.2. Self-Perception and Academic Performance.

A stereotype is an individuals set of beliefs about the characteristics or attributes of a group (Judd and Park, 1993). A study by Broverman, Vogel, Broverman, Clarkson and Rosenkrantz (1972) found that males were described more often than females in terms of intellectual competence, whereas females were described for their warmth and expressiveness. On the negative side, females were also described as incompetent and passive.

In Feldman-Summers (1994) study of the phenomenon of attribution, of which stereotyping is a special case, she found that when students were introduced to a highly successful female physician, the male under-graduates perceived her as being less competent and having had an easier path to success than would a successful male physician. Female students perceived the male and female physicians as being equally competent but that the male physician would have had an easier time reaching success in his career. Both the males and females attributed higher motivation to the female physician. Attributing high degrees of motivation to a female can imply that she has less actual skill than her male counterpart.

Nicholl (1992) found that as early as fourth grade, boys attributed their own successes in intellectual tasks to ability whereas girls derogated their performance, often putting it down to “fluke” or chance. Boys, however, viewed failure, as bad luck, whereas girls took the blame for their failure, usually in terms of inability. How a person attributes their failure in a particular task will determine their success in subsequent tasks.

4.17.3. Stereotyping In Academia.

A concern voiced with regards to research into the accuracy of stereotyping is the fear such research would result in the unintentional communication to society that stereotypes are accurate and can be used as a basis for judging others (Beyer, (1999), Goldberg, (1968) and Pheterson, Kiesler and Goldberg (1971). Their research looked at stereotyping in the academic area that is likely to have consequences for the choice of major and ultimate profession. Among their many

results, they found that females were even more likely than males to overestimate males compared to females' grades in masculine majors. However, it has to be said that female self-perception and their views on gender roles may well have changed in the last 30 years. It is the intention of this present study to manipulate participant self-perception to see if there is a direct effect on performance in a mental rotation test.

Beyer's study found that in reality, the female grades were higher than the males in all of the 12 majors used in the study. Beyer suggested that if female participants remain unaware of the fact female students in masculine domains actually do better than their male counterparts they will not be encouraged to venture into gender-incongruent majors.

4.17.4. Parental Expectations.

A study by Olszewski-Kubilius and Yasumoto (1994) found that parental feelings about the importance of subjects could affect student self-perceptions, particularly for females, which prevents them from "accelerating themselves in mathematics" (pg 3). Students whose parents rated mathematics as more important than verbal courses to their child's future were more likely to choose to study mathematics at summer schools. Further, academically talented males participated in extra-curricular activities in science more than did females, thereby increasing their knowledge of science, increasing their confidence and motivation to study science in accelerated courses with other bright students. Their findings support those of Meece, Parsons, Kaczala, Goff and Futterman (1982) who added that by discouraging females from majors such as maths and science in itself decreases

their chances of learning spatial skills as such courses produce improvement on mental rotation ability (Burnett and Lane, 1971)

The overall results of Beyer's research suggested that females are still perceived as less capable than males in traditionally masculine majors and therefore arrive at university with entrenched beliefs about the appropriateness and difficulty of various majors for them. Beyer stated that institutional efforts to attract students to gender-incongruent majors may be fruitless until such time that such gender stereotypes are dispelled.

4.17.5 The Perpetuation Of Stereotypical Gender Roles Through Computer Games.

It has already been stated that females are less confident than boys with regards to computer ability and that computer games are targeted at a male audience (Admin, 2001). On top of these major hurdles are the roles females are given in computer games. The majority of current computer games reaffirm the age-old doctrine of dominant and patriarchal conceptions of gender roles by depicting males as heroes and females as victims. Preteen girls face an even greater loss of self-esteem, confidence and motivation if they are faced with a culture that consistently devalues their interests, skills and abilities.

In the short history of computer games, there are few female characters. When they are included, their exaggerated features are intended to appeal to younger males. In order to encourage more females to play games, female characters are needed that girls can relate to with skills that are equal to the male characters

(Wright 2000). An annual revue by Childrens Software Revue found that in the year 2000 only 13 new programs broke from gender stereotypes without the usual focus on shopping, and fashion and that there were five times as many male lead characters as female. Stereotyping via the medium of computer games can greatly influence beliefs about the group being stereotyped often to the point that the stereotyped group accepts these characteristics (Seels, Berry, Fullerton and Horn, 1999). It is stereotyping that contributes to gender segregation with relation to computers and might explain why so few females want to work in technology. One way of improving the negative stereotyping is by using positive imagery portrayed to the general public. This imagery would show females in productive roles using technology in powerful ways and should be extended to the images of women in computer games.

4.18. Summary.

Although there is a great deal of evidence to explain the evolution of sex differences, it would, of course, be biologically unsound to say that females are not as interested in computers and VR due to evolutionary reasons as obviously there were no computers around in the Pleistocene Age. It would also be unrealistic to say that females have a genetic predisposition to dislike computers when they were never part of the “hunter-gatherer” environment. However, computers in general, and "shoot'em up" computer games in particular are not attractive to females for these very bio-motivational reasons.

This chapter has discussed the biological reasons for sex differences and their possible evolutionary development. There is overwhelming evidence to support

the nature argument for sex differences, however the nurture argument cannot be ignored. Gender roles and parental expectations shape how boys and girls perceive their world and their own actions within it. Educational establishments can encourage the differences, often at an unconscious level. Motivation, practice and self-perception have been focused upon as three major environmental influences that can affect behaviour, often in a negative way.

With regards to VR and spatial ability, special attention has been given to the role of the computer games companies. It has been recognised that games are an introduction to computer literacy and that games can improve spatial skills and interface proficiency. Girls are being discouraged from taking an active involvement in gaming because of the male orientated content of most games and the often negative representations of females. It was argued that games designers have a responsibility to both males and females so that both have equal opportunities to enter the world of digital technology. The reason gaming is so important is not only because practice can improve spatial skills but for the very reason that this study is being carried out. Females are under-performing within VR as explained in chapter one and sex differences are one form of explanation. It is possible that lack of experience and lack of motivation to interact with computer technology are also important issues to be addressed.

The next three chapters will investigate sex differences in mental rotation performance using both 2D and 3D representations. Environmental factors will be used to manipulate performance in order to understand the effects of self-perception, motivation and practice on the performance of mental rotation tasks.

Performance within a familiar VE will also test orientation, navigation, route learning and mental rotation, taking into consideration the participants age, sex and math ability along with prior computer and game playing experience.

Chapter Five

Phase one experiments

Introduction

The purpose of this study is to investigate the findings that there are significant gender differences, favouring males; in mental rotation tasks and to ascertain whether or not this ability is an accurate predictor of performance within a VE. The justification for such research lies in contemporary studies of performance within VR, outlined in chapter one, which also show significant gender differences, favouring males.

As stated previously, this is a concern as more and more VR is being used for educational and training purposes as well as for entertainment. Successful performance within VR involves space perception, navigational skills, tracking, cognitive-map development and maintenance, distance perception and spatial knowledge representation techniques. An important component of spatial visualisation is mental rotation and males have the greater spatial/quantitative aptitude. It is the ability to visualise objects in space that some researchers believe underlies the gender differences in quantitative aptitude and achievement.

5.1. Purdue Visualisation of Rotations Test (ROT)

In this first stage of testing, mental rotation ability was tested to see if gender differences would be found in both 2D and 3D spatial tasks. The first test was the paper and pencil 2D Purdue Visualisation of Rotations Test (ROT), this was partly because a large number of participants could be accessed quickly and easily without the need for computers and accompanying technology. A further

justification was that in a number of engineering and chemistry faculties in universities use the ROT to assess first year students, (Sorby and Baartman, 1996), Bodner, 1989). George Bodner (1989), co-developer of the ROT, stated that there is a correlation between spatial ability and problem solving performance and the results of such a test can predict which students will have difficulty abstracting relevant information from two-dimensional models projected on a computer screen. The spatial visualisation factor contained within this test measures the participants ability to mentally restructure or manipulate the components of the visual stimulus, which involves recognising, retaining and recalling configurations when the figures are moved.

Bodner considered the problem of whether spatial tests actually measure the cognitive tasks generally recognised as spatial ability. It has long since been recognised that spatial tasks can be solved in different ways, suggesting that the cognitive processing strategy used to answer the test determines the ability the task actually measures. It has also been suggested that gender differences in spatial ability result from differences in the way spatial tasks are processed. Bodner hypothesised that there are two major processing strategies used to solve spatial tasks. One strategy is Gestalt processing whereby an individual forms and transforms visual images as an organised whole. The other process is called Analytic processing where the whole is broken into individual parts and its relationship is mapped in a one to one process. Bodner cited several researchers who have accepted Gestalt processing as the key cognitive component of spatial ability although many spatial tests require only a small amount of Gestalt processing but in fact need a significant amount of analytic processing.

The development of the ROT assumed that existing spatial ability tests vary in the amount of Gestalt and Analytical processing required and that tests maximising Gestalt processing, whilst minimising analytical processing, are the most appropriate measures of spatial ability. In his test, analytic processing was minimised by putting a time limit of ten minutes on the 20-item test. The ROT differs from the original Shepard and Metzler MRT (SM) in two important ways. Whereas rotation in the original SM test is restricted to the plane of the drawing or a vertical axis running through the drawing, the axis of rotation in the ROT test corresponds to a natural axis of the object. Shepard and Metzler also avoided drawings that contained singularities with hidden parts, the ROT contains questions in which either characteristic aspects of the object are hidden from view or in which the object is rotated around more than one axis.

The test used in this present study was only one element of the Purdue Spatial Visualisation Test Battery devised by Bodner and Guay (1977). The ROT was revised and shortened by Bodner (1989) for the purposes of assessing first year students whilst retaining its validity and reliability. Although originally a 30-item test, 10 items were removed. The ROT was obtained from Bodner (personal correspondence) along with the instructions for carrying out the test.

5.2. Shepard and Metzler Mental Rotation Test:

An important reason for using Shepard and Metzler (1971) or indeed Vandenburg and Kuse (1978) style mental rotation tests can be explained by referring to the previously mentioned meta-analysis cited in MacIntyre, 1997 (see chapter four). The meta-analysis table showed that the mental rotation task as set by Stumpf and Kliene (1989), which is a cube perspective test, has reduced from a large effect

size of 0.77 in 1978 to only 0.38 in 1987. Spatial visualisation tasks in the way of the Group Embedded Figures Test had only an effect size of 0.13 indicating a massive overlap in scores. The EFT had an effect size of 0.44. However, as it has been shown to be open to interpretation bias, experimenter expectancy and observer effects, the author decided it was not to be used as a spatial abilities test. These meta-analysis findings indicated that the male superiority on spatial ability appears to be diminishing. However, the Group Mental Rotations Test still showed a dramatic effect size of 0.73, favouring the male population. In 1986 Linn and Peterson also found a large effect size in the Group Mental Rotation test, favouring males.

Voyer, Voyer and Bryden (1995) also supported the findings that many of the gender differences found in spatial tests are diminishing except, generally speaking, the mental rotation test. They found a large difference, favouring males, on a Vandenburg and Kuse three-dimensional mental rotation task. Out of the three visio-spatial task categories, (mental rotation, spatial perception and spatial visualisation) it was mental rotation that showed the largest difference with an effect size $d = .94$. There were only small or medium effects for spatial visualisation and spatial perception.

Their research showed that although differences existed on many tasks, testing procedures affected their magnitude. Their meta-analysis suggested, among others, that procedural factors should be considered when examining the magnitude of gender differences in spatial skills. Time pressure and scoring procedures particularly affected the magnitude of gender differences in spatial

abilities. In fact, they found that gender differences were often not significant when time pressures were removed, supporting an interpretation in terms of how men and women approach the task.

With these considerations it was decided, in the first instance, to use the paper and pencil Purdue Visualisation of Rotations Test, a test known for its validity and reliability (Bodner, 1989). The test required the participant to use Gestalt or Holistic processing.

Two further mental rotation tests were administered to participants, both of which were computer generated. These MRTs were presented on a computer screen and viewed through shutterglasses that created the illusion of 3D. This is the same principle as used in 3D VR systems although the sophistication of the hardware increases in price from the relatively inexpensive shutterglasses used with many commercially available games to costly head mounted displays complete with data gloves and haptic feedback. The aim of using 2D and 3D MRTs was to see if gender differences regarding MRTs were found in both forms of presentation.

A standard SM style “wire-frame” MRT was administered using the 3D imaging techniques. The “wire-frame” shapes were transparent, and provided excellent cues to depth by the use of perspective. Perspective and its importance to depth perception were described in chapter three and are important to virtual environments in order to create the illusion of three-dimensions and realistic scenes. As humans, we try to impose meaning on what we see in the world by seeking to turn images into objects wherever possible. One such imposition is that

of depth which can be interpreted as trying to make shapes more like tangible 3D objects. We find it difficult to avoid interpreting converging lines as indicating linear perspective. Converging lines are perceived as showing depth even in a simple line drawing because the visual system tends to interpret converging lines as remaining parallel in depth.

A third 3D test was used whereby the same shapes as used in the “wire-frame” test were utilised except they were “solid” in nature. Adding shadow, as described in chapter three, created the appearance of depth. Shadowing and texturing are important to the design of VEs, as they are needed to ensure images look as lifelike as possible. In a virtual world, particularly if fully-immersive, the intention is to create a much more lifelike environment, ideally to the point where the viewer should not be aware of being in a computer generated world ((Mills and Noyes, 1999). Ramachandran emphasised the importance of shading for depth perception. However, he stated that shading only gives a weak impression of three-dimensional shape but when a shaded surface is enclosed by an outline, this gives a credible impression of depth. By adding an outline or border, any information from ambiguous shading cues is resolved, demonstrating that the brain recovers information about the shape of objects by combining outlines and shading cues.

By removing the wire frames, an element of complexity was added to the test. The second “wire-frame” test, according to Bodner (1997) would be solved using Analytical processing whereas the third test was an unknown in that it was more a hybrid of both the ROT and the “wire-frame” test. Although the “solid” test

required the participant to make comparisons and judgements between two shapes as in the “wire-frame test” therefore using Analytical processing, it also required the participant to mentally rotate at least one of the shapes due to the effects of occlusion, utilising Analogue processing.

The justification for the three tests was to see if the expected gender difference in mental rotation ability would be evidenced in the standard 2D paper and pencil test, would decrease or disappear in the 3D wire-frame test” due to the added bonus of the third dimension (as posited by Larson, 1999) and the difference would again be evidenced when the benefit of 3D was reduced by making the shapes opaque and therefore adding to task complexity.

5.3. Experiment 1.

Purdue Visualisation of Rotation

As previously explained, visio-spatial skills, such as mental rotation, influences human functioning at many levels ranging from navigating the environment to choosing a career path. Many occupations, such as architecture, engineering, chemistry and surgery require high levels of visio-spatial competency, all of which are generally considered to be male orientated careers. They are also subjects that require mathematical competencies for success. Casey, Nuttall and Pezaris (1997), Geary (1996) Kimura (1992) and Benbow (1988, Burnett and Lane, 1971, Casey, 1996) amongst others, believe that mathematical ability and visio-spatial ability are related.

As VR is being used not only for entertainment reasons but also for education and training purposes, including the aforementioned subjects, it is important to

discover why females tend to perform poorly within VR and consequently to see if there is a relationship between spatial ability and math ability (see chapter seven, phase three testing). Mental rotation is necessary for successful navigation and is the most consistent spatial test to still show a robust gender difference. For this reason the Purdue Visualisation of Rotations Test (ROT) was considered an appropriate paper and pencil test to administer. The ROT is a two-dimensional task because the stimuli are two-dimensional representations of three-dimensional objects. The test is timed in that participants had 10 minutes to complete the 20 questions.

The hypothesis, based on afore-mentioned literature, was that there would be a male advantage on this spatial ability test. For fuller interpretation of the data, further factors were included. Faculty was added as a factor with the understanding that participants in the Science and Engineering Faculty should perform better than the participants in the Arts and Social Science faculty, as math is an important entrance requirement for the Sciences but not for the Arts (Voyer, Voyer and Bryden, 1995).

There were two hypotheses:

- 1) Males would give more correct responses in the ROT than the females.
- 2) Science and Engineering participants would give more correct responses in the ROT than the Arts and Social Science participants.

The Method

5.4. The Design

The experimental method and independent groups design was used (Item 7 from the 20-item ROT test is shown in Figure 5.1). There were two Independent Variables, Gender (male/female) and Faculty (Arts and Social Sciences/Science and Engineering) the interactions between the factors were also analysed. The dependent variable was mental rotation ability as measured by the number of correct answers given on the MRT. Scoring was simply calculated as per the instructions accompanying the test in that for every correct answer, the participant scored one point. (A copy of the test paper can be viewed in appendix 1)

Participants:

Quota sampling was used to select the 100 participants, 55 males and 45 females, all were right handed and all were either students or academic staff whose discipline fell under one of two faculty headings i.e. Science and Engineering or Arts and Social Sciences. Forty were Arts, of which 15 were male and 25 female, 60 were Science of which 35 were male and 25 were female. A reward of £5 was paid to the students volunteering to take part in the test. All subjects had normal or corrected to normal vision.

Apparatus:

The Purdue Visualisation of Rotations Test was administered, comprising of 20 questions, an example of which can be seen in Fig.5.1. The items were 2D representations of 3D shapes produced on paper and were presented two items to a page. A standard sports stopwatch was used to time the ten-minute trial. A sheet of A4 paper was supplied for participants, in order to record their responses, age, sex and faculty. SPSS statistical package was used for data analysis.

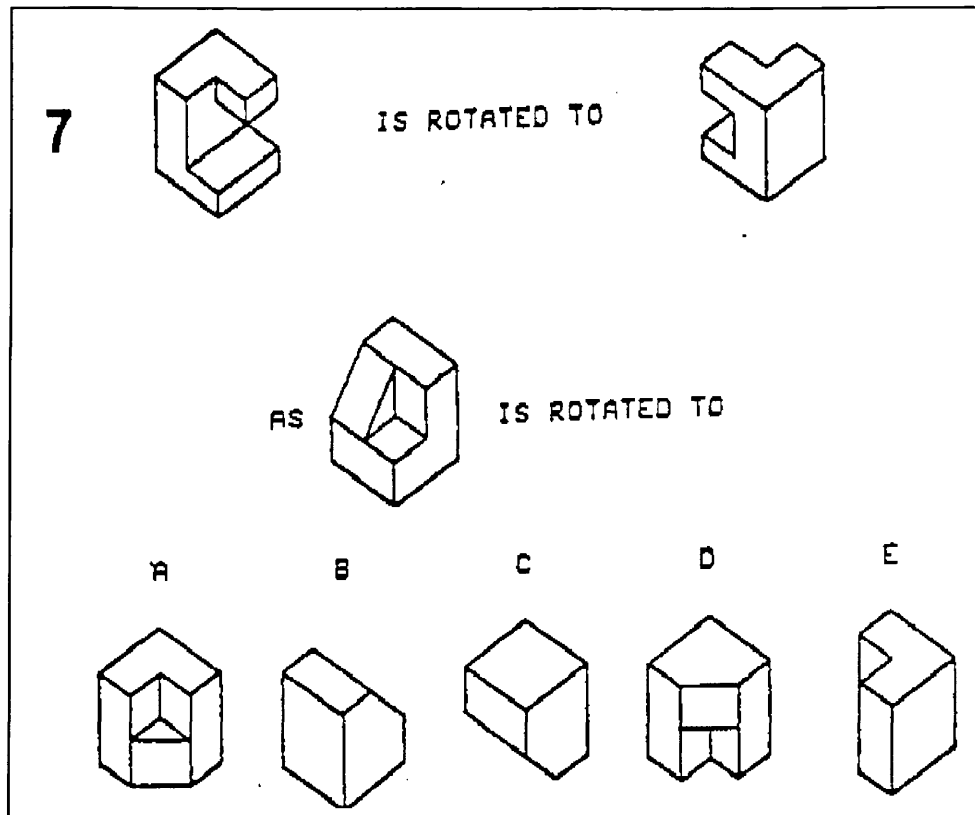


Figure 5.1. Item 7 from the 20-item version of the Purdue Visualisation of Rotations (ROT) test. Copyright, Purdue Research Foundation.

Procedure:

Participants were tested in a laboratory setting, whereby the testing procedure involved participants completing the ROT. Participants were tested on their own.

The ROT is a paper and pencil task, which required the participant to:

1. Study how the object in the top line of the question is rotated,
2. Picture in their mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner, and
3. To select from among the five drawings (ABCD or E) given in the bottom line of the question, the one that looks like the object rotated in the correct position (see Fig5.1).

The instructions plus 2 trial items were given to the participants to read and understand. Only when the participant confirmed that they understood what they had to do, did the test commence. The participant was informed that they had ten minutes in which to complete as many of the 20 item questions as possible. They were told when they had two minutes left out of the ten and were then informed when the ten minutes had been completed. If the participant requested to know how well they had performed, the correct answers were read out to them to compare with their own responses. The number of correct responses made by each participant was recorded on a database for analysis.

5.4.1. Results of the ROT:

Accuracy:

The data indicated that male and female performance in the 2D mental rotation test did not differ overall in their capacity to answer correctly (means of 13.87, S.D. 3.94 and 13.11, S.D. 3.49 respectively). This also applied to the Arts and Social Science and Science and Engineering participants (means of 12.55, S.D. 3.71 and 14.18, S.D. 3.65 respectively)

The number of correct answers were analysed using a factorial analysis of variance with two between-participant factors of Gender (male and females) and Faculty (Arts and Social Sciences and Science and Engineers) This analysis revealed that the main effects due to Gender ($F(1,92) = 0.1, p > 0.05, p = .75$) and Faculty ($F(1,92) = 2.29, p > 0.05, p = .133$) were not significant.

The interactions between Genders by Faculty ($F(1,92) = .009, p > 0.05, p = .92$) were also not significant.

5.4.2. Discussion:

The results did not support the hypotheses in that the males did not outperform the females in fact their mean was remarkably similar, the Sciences did not significantly outperform the Arts although they did score marginally higher and there was an insignificant difference in performance in the age groups.

This is a surprising result as it is contrary to the expected, suggesting that something other than sex differences affected performance. What had not been taken into account were previous experiences that may have had a positive effect on spatial skills. Such experiences might include the number of years an individual has been using a computer or playing computer games. As discussed in chapter four, computer literacy and gaming experience can improve spatial skills. McClurg and Chaille (1987) found that certain computer games enhanced the development of spatial ability measured by a mental rotation test and Murphy (2001) wrote that video games are the technological equivalent to giving a child a “headstart” as computer based games prepare children not only for their participation in the digital world but can also improve cognitive skills including the maintenance of attention and orienting objects in space. Other experiences such as sports participation and forms of employment such as architecture, engineering and even flower arranging can also increase spatial skills through practice although the basis for such choices may indeed be biologically determined with regards to an innate spatial ability.

It would be presumptive and somewhat foolish to claim that sex differences in mental rotation have been eradicated due to the findings of one test. However, important issues have been raised which are worthy of further research. In the

second phase of experiments environmental factors will be considered other than purely sex differences. In the third phase of testing maths ability, computer experience and computer games experience will be taken into consideration along with sex, age and the faculty to which the participants belong.

5.5 Experiment two: 3D “Wire frame” Test

Notwithstanding the results found in experiment one, mental rotation tests generally produce gender differences favouring males. The ROT test was a 2D paper and pencil test and the gender differences in mental rotation ability that are relevant to this present research refer to performance within VR. A 3D MRT was necessary to see if gender differences continue when the third dimension is supplied.

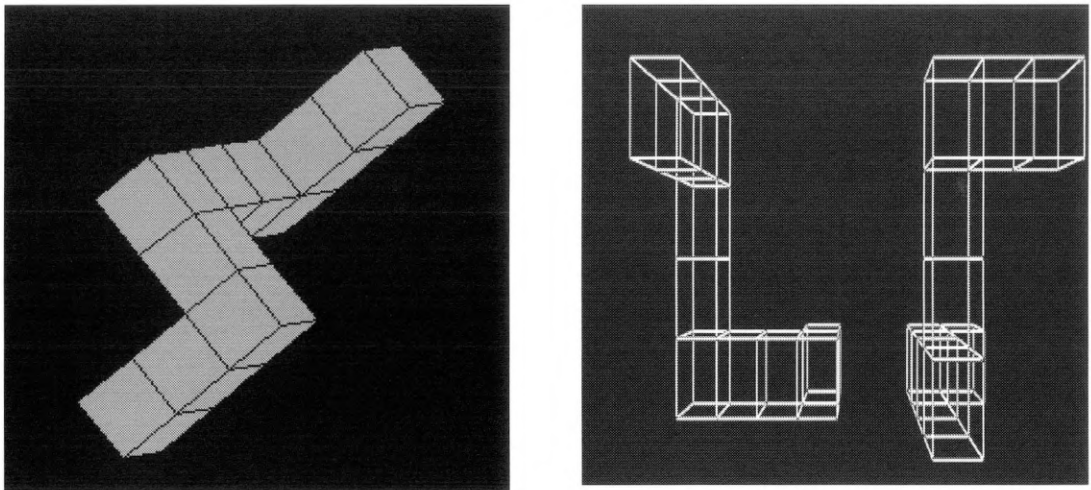


Figure 5.2 shows the Shepard and Metzler (1971) style stimuli on the left and a pair of “transparent” stimuli from experiment two.

In experiment two, participants were asked to complete a 3D mental rotation test similar to the Shepard and Metzler (1971) and later, the Vandenburg and Kuse (1978) mental rotation test. There are two major differences, the first being that the present stimuli are transparent whereas the standard stimuli were not. This

can be explained by looking at Fig 5.2, the Shepard and Metzler style shape is on the left and the transparent shape is on the right. Both however avoid the problem of occlusion as in the SM shapes, they are positioned in such a way that it is obvious to the viewer the arrangement that is out of view. In the “wire-frame” shape there is no occlusion.

The second difference is that the transparent or “wire-frame” shapes were presented on a computer screen and viewed via shutterglasses, creating the impression of three-dimensionality (see figures 5.3, 5.4 and 5.5). Larson (1999) stated that presenting the shapes in 3D might overcome the problems females have in mentally visualising three-dimensional shapes.

Apart from the bonus of three-dimensionality, the fact that the “wire-frame” shapes were transparent may help when comparing stimuli. The object of the test was to decide if the paired shape on the right was the same as the standard shape on the left and therefore giving a “yes” response. If it was thought that the shape was different or a mirror image of the standard then a “No” response would be given.

Not only were the stimuli transparent, the wire-frame also gave a clear indication of perspective. Perspective, as already mentioned in chapter three, is a major cue to depth perception. The illusion of depth is fundamental to VR and the creation of virtual environments. The ability to perceive depth whilst navigating a virtual environment allows the navigator to translate the information being depicted by the VR system. The ability to mentally rotate and visualise enables the navigator

to keep track of where they have been and where they are about to go without becoming disorientated. Using 3D and the further visual depth cue of perspective should have the effect of decreasing differences in performance which are traditionally found between the males and females on MRTs and may give an indication to how performances in VR can be improved.

How we perceive depth by using perspective as a cue has been discussed at length in chapter three, section 3.4, therefore does not require further explanation at this stage.

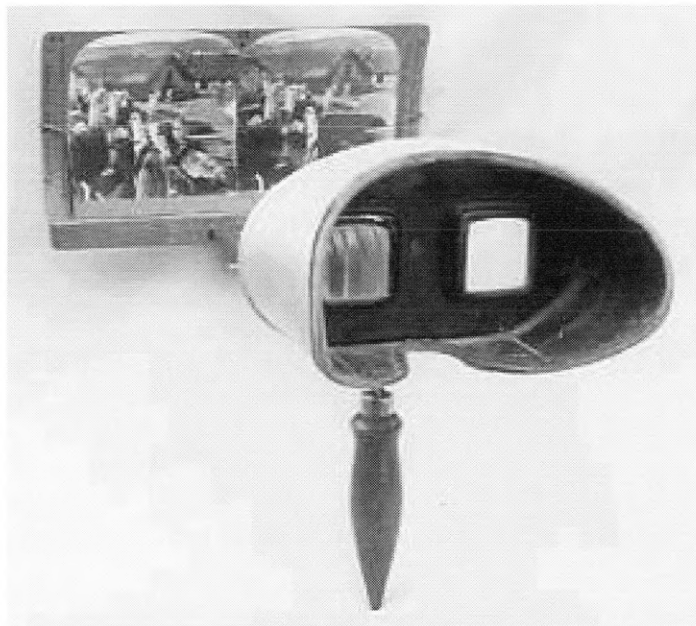


Fig 5.3 shows an old style stereoscopic viewer where the two images are fused together to create a three-dimensional image

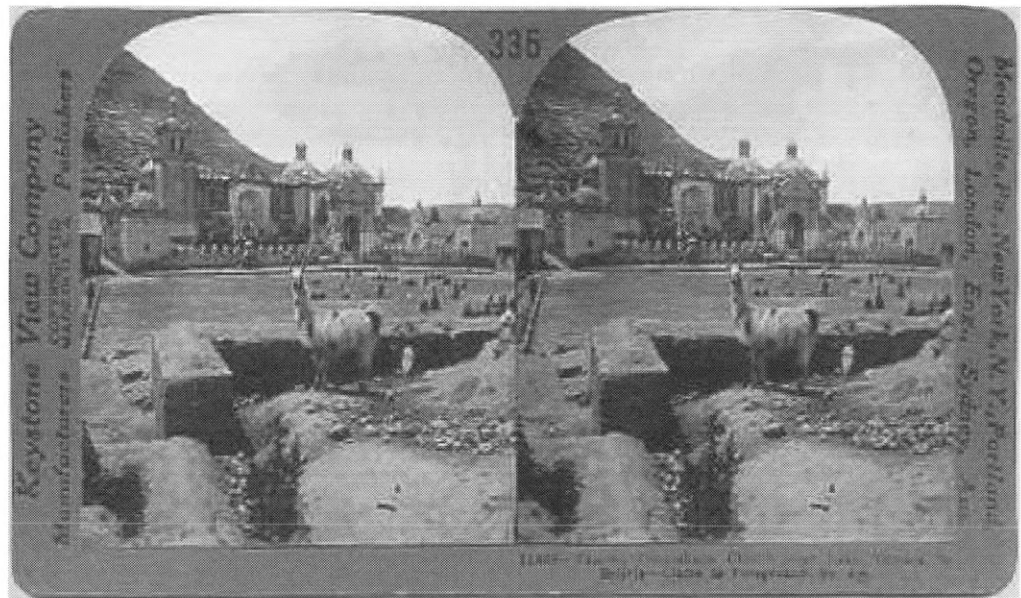


Fig 5.4 shows an example of an old style stereo card that was viewed through a stereoscope in order to create a three-dimensional image. *(Copyright of the Keystone View Company)*



Fig 5.5 shows the type of 3D Elsa shutter glasses used to view the virtual house.

How the 3D effect works.

Our ability to see stereovision comes from our two eyes seeing a slightly different view of the world. Our brain integrates these two images into one three-dimensional picture. The key element, as discussed in chapter three, to producing the stereoscopic depth effect is parallax, which is the horizontal distance between corresponding left and right image points. The stereoscopic image is made up of two images generated from two related perspective viewpoints and the viewpoints are responsible for the parallax content of the view. The LCD shutterglasses used in the 3D experiments create the illusion of depth because the left and right images are alternated rapidly on the monitor screen. When the viewer looks at the screen through the shutterglasses, each shutter is synchronised to occlude the unwanted image and transmit the wanted image. Each eye therefore sees only its appropriate perspective view. If the images are flashed fast enough (usually twice the rate of the planar display), the result is a flickerless stereoscopic image.

5.5.1 Present Experiment

As this present research was concerned with performance within Virtual Reality, it was necessary to introduce a mental rotation test that could be viewed in 3D. In this case, wire-frame Shepard and Metzler style shapes were used. When the shapes were viewed without the aid of shutterglasses, there was, to some viewers, the perception of changing depth when looking at certain areas of the shape for any given length of time. As in the wire-frame Necker cube, there were ambiguities in depth (see chapter three, 3.4.4), however when wearing the shutterglasses the ambiguities disappeared and the shape was seen as three-dimensional.

The shapes were comprised of ten “Necker cube” style rhomboids joined together, however the properties of perspective aided the perception of depth. The fact that the shapes were transparent gave extra cues to the viewer when comparing the standard shape to the rotated shape. Without the transparency, the rotation of the shape would normally mean that there would be the occlusion of certain parts from view but as the shape was transparent this did not come into force.

As mentioned previously, the Shepard and Metzler rotations test was later adapted for group testing by Vandenberg and Kuse and it was a similar version of this test that was chosen. The comparison shapes from which the participants had to make their decisions were:

1. The same as the standard shape but rotated in depth or in the plane.
2. The mirror image of the standard shape.
3. Or completely different from the standard shape.

The participant had to make “Yes” or “No” answers, Yes the shapes were the same or No they were either mirror images or different. An extra element was added to the second test, not present in the ROT, in that the participants were timed. They were not given a time restriction as such, but were told that speed and accuracy were being recorded.

Although Larson (1999) predicted that females might perform better on 3D MRTs, the hypotheses continue to reflect those used in experiment one. As there was a timed element to this test and as it is known that females perform less well

under time pressures (Voyer, Bryden and Voyer, 1995) a prediction with reference to the time taken to complete the MRT was added.

The two hypotheses were:

1. Males would be more accurate and faster in completing the wire-frame MRT than the females.
2. Science and Engineering participants would be more accurate and faster in completing the wire-frame MRT than the Arts and Social Science participants.

The Method:

5.5.2 The Design

The experimental method and independent groups design was used. The independent variables were Gender (male and female) and Faculty (Arts and Social Science and Science and Engineering) and the dependent variables were mental rotation ability as in the number of correct answers given and the time taken to complete the test. The interactions between the factors were also analysed.

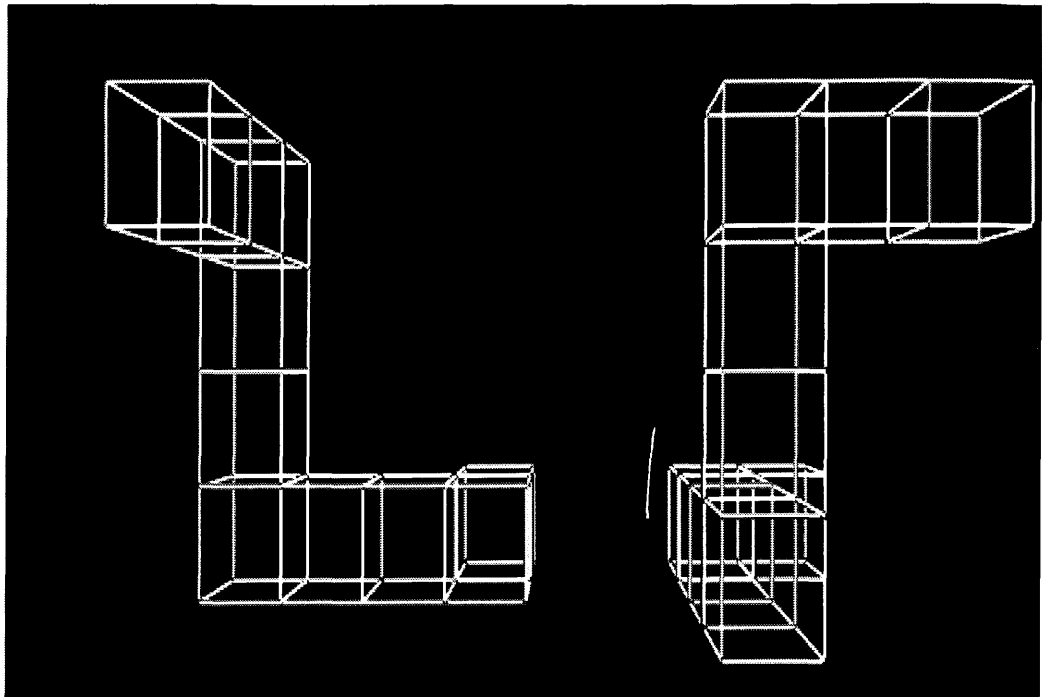


Fig 5.6 shows one question from the 3D wire-frame test where the participant was requested to decide if the shape on the right was the same or different from the shape on the left. The shapes were viewed wearing 3D shutter glasses.

Participants

Quota sampling was used to select the 61 participants, 28 males and 33 females. All were right handed and all were either students or academic staff whose discipline fell under one of two faculty headings i.e. Science and Engineering or Arts and Social Sciences. Twenty-eight were Arts of which 11 were male and 17 female, 33 were Science of which 17 were male and 16 were female. Twenty-seven was the mean age of the participants, 17 was the youngest participant and 48 the oldest. A reward of £5 was paid to the participants who volunteered to take part in the test. All participants had normal or corrected to normal vision and had not participated in previous MRTs.

Apparatus

Elsa Shutterglasses were used to view the 60 pairs of shapes, which were presented on a Samsung computer screen (see figure 5.6). For this experiment, a 3D style version of Shepard and Metzler's mental rotation test was designed. A computer program, using World Toolkit Sense8, created 60 pairs of Shepard and Metzler style wire-frame shapes. There were 12 standard shapes each of which comprised of 10 cubes (See Fig 5.7). The comparison shapes were either rotated versions of the standard, a mirror image or a different shape. Twelve of the comparison shapes were rotated 90 degrees in the plane and twelve were rotated 180 degrees in the plane. Twelve were rotated 90 degrees in depth and a further twelve rotated 180 degrees in depth. Six were mirror images and six were different shapes. The pairs of shapes were presented randomly so that no two participants received the pairs in the same order.

There was a 2 second fixation spot presented after every decision key was pressed to ensure that the participants eyes were focused on the centre of the screen. The shutterglasses created the impression of three-dimensional shapes. The program was designed to include a "Notepad" facility that stored not only the correct response for each pair but also the actual response given by the subject. The time for each response was also recorded i.e. the time taken from when the pair of shapes were first displayed to the moment the subject pressed a "Y" or "N" decision key on the computer keyboard. The total time taken to complete the test was also recorded on "Notepad".

Procedure

Participants were tested individually under laboratory conditions. The experiment required the participant to complete a 60 item mental rotation task where they were to compare two figures and decide if they were the “same” but in different orientations or if they were “different” i.e. a mirror image or a completely different shapes. Participants viewed the 3D figures via shutterglasses giving depth projection as would be experienced in virtual environments. In this second experiment, the participants response rates and accuracy were recorded. The shapes were presented in a computer generated, random order for each participant.

The experimenter explained the instructions to the participant while they viewed a trial pair of shapes on the computer screen. The experimenter confirmed that the participant was comfortable and that they could see in stereopsis without any visual discomfort.

The instructions to the participant advised that they should compare the shape on the right of the screen to the shape on the left of the screen. The participant was then to decide if the shape on the right was the same as the shape on the left other than being in a different position in the plane or in depth. If the participant thought that the shape on the right was the same as the one on the left, they were instructed to press the “y” button on the keyboard for “yes” it was the same shape. If they thought the shape on the right was completely different shape or a mirror image of the shape on the left, then they were to press the “N” key for “No” the shapes were not the same.

If a participant needed further explanations, such as to clarify the meaning of “plane”, the instructions were repeated in a more simplified manner until the participant was clear as to what was expected of them. The participant then carried out a trial of 12 pairs of shapes during which time they were free to ask further questions. Once the participant was relaxed and sure of the instructions, the experimenter then explained that the actual experiment contained 60 pairs of shapes. The participant was asked to make their “Yes” or “No” decisions as quickly and as accurately as possible but not one at the detriment of the other. It was explained that the computer presented the shapes randomly and that they were not to think that there were “trick” pairs as sometimes they may feel that they were pressing the same decision button continuously, that was just the nature of the random procedure. The randomisation was to control for order effects such as boredom and practice, no two participants were presented with the shapes in the same order. Only when the participant said they were ready was the test began, starting with a fixation spot. Importantly, the terms “rotation” or “rotated” were not used as such terminology might indicate to the participant the type of strategy to use in order to solve the task.

At the end of the test the participants were given the opportunity to see how they scored. The scoring procedure was different from the standard Shepard and Metzler and Vandenburg and Kuse type mental rotation tests. In the standard tests, the researchers used only the “correct same” answers, as they were interested in the reaction time taken to make a comparison between shapes, they found that reaction time is a linear function of the rotation angle. In this present

test all correct answers were included. Scoring was simply a point awarded for each correct answer.

5.5.3 Results For The Wire-Frame Test

Number of correct answers:

The data were analysed and the results indicated that male and female performance in the wire-frame mental rotation test did not differ overall in their capacity to answer correctly (means of 51, S.D. 7.59 and 51.97, S.D. 6.98 respectively). With the Faculty condition, the results showed that the Science and Engineering participants scored more correct answers than did the Arts and Social Science participants (means of 54.03, S.D. 5.4 and 49.07, S.D. 8.2 respectively).

The number of correct answers in the wire-frame test was analysed using a factorial analysis of variance with two between-participant factors of Gender (male and females) and Faculty (Arts and Social Sciences and Science and Engineers) This analysis revealed that the main effect due to Gender ($F(1,53) = 0.171, p > 0.05, p = .68$) was not significant but, the main effect of Faculty was significant ($F(1,53) = 8.9, p < 0.05, p = .004$)

The interactions between Genders by Faculty ($F(1,53) = .33, p > 0.05, p = .57$), was not significant.

5.5.4. Time Taken To Complete The 3D “Wire-Frame” Test.

The data was analysed and the results showed that the male and female performance regarding the time taken to complete the wire-frame mental rotation test did not differ overall (means of 556.43s, S.D.=260.06s and 488.1s,

S.D.=275.45s respectively). With the Faculty condition the results showed that the Science and Engineering participants took longer than the Arts and Social Science participants (means of 523.48s, S.D.= 248.06s and 514.13s, S.D.= 295.28s respectively).

The time taken to complete the wire-frame test was analysed using a factorial analysis of variance with two between-participant factors of Gender (male and females) and Faculty (Arts and Social Sciences and Science and Engineering). This analysis revealed that the main effects due to Gender ($F(1,49) = 0.830$, $p > 0.05$, $p = .37$) and Faculty ($F(1,49) = .004$, $p < 0.05$, $p = .95$) were not significant.

The interaction between Genders by Faculty ($F(1,49) = .4.74$, $p < 0.05$, $p = .03$) was significant as illustrated in Fig 5.7.

Analysis of variance (ANOVA) revealed a significant difference between the males in the Arts and Social Science Faculty and in the Science and Engineering Faculty ($F(1,26) = 4.27$, $p < 0.05$, $p = .049$) with means of 437.19s S.D. 133.99 and 633.5s S.D. 294.64 respectively.

There was no significant difference between the Females and Faculty ($F(1,31) = 2.81$, $p > 0.05$, $p = .1$) with means of 563.9s, S.D. 359.46 for the participants in the Arts and Social Sciences and 407.54s, S.D. 102.95 for the Science and Engineering participants.

These results indicated that the Females in the Arts and Social Science Faculty were slower than the Females in the Science and Engineering Faculty whereas the

Males in the Science and Engineering Faculty were significantly slower than the Males Arts.

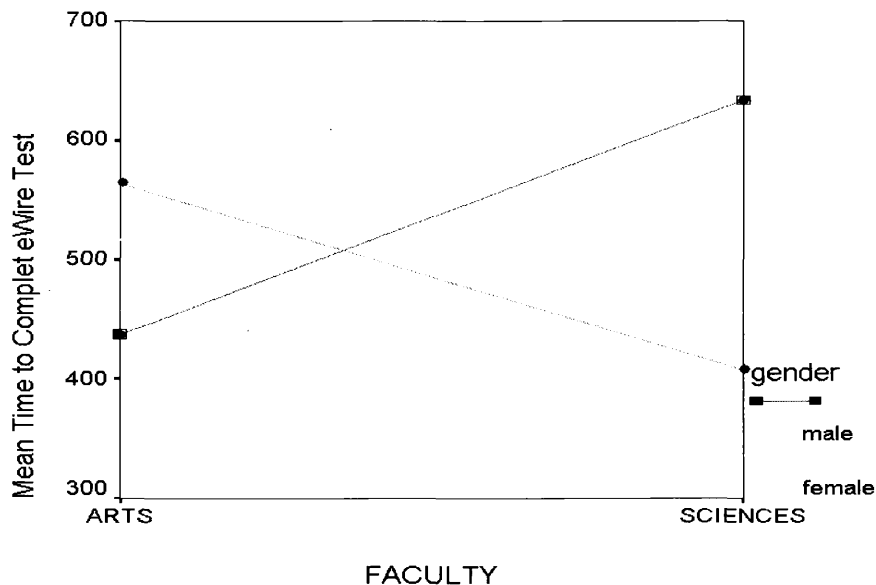


Figure 5.7. Graph showing the interaction between Gender and Faculty in the time (in seconds) taken to complete the wire-frame 3D Mental Rotation Test

5.5.5. Discussion

Again, as in experiment one, the results were not as expected and did not support the hypotheses that the males would be faster and more accurate than the females. Only Faculty revealed a significant difference as predicted, with the Sciences outperforming the Arts.

With regards to completion time there were no significant differences with regards to Gender or Faculty. However, the interaction between Gender and Faculty was interesting in that the Male Arts were significantly faster than the Male Sciences. This might indicate that they were using different strategies, for example, the Arts students, having a lesser aptitude for math (Voyer, Voyer and Bryden, 1995), therefore having poorer spatial ability (Casey, 1996) may have

been using a strategy that did not rely on mental rotation ability. They perhaps used a more language-based strategy or it is possible that the Males Arts used a more Gestalt or analogue form of processing and the Male Sciences used propositional or analytical processing resulting in a longer time to make their decisions.

When looking at the female results, it can be seen that there was no significant difference in speed although the roles were reversed, with the Female Sciences performing faster than the Female Arts. A possible explanation might be the difference in spatial skills with the females in the Sciences having an initial spatial ability advantage reinforced by practice i.e. taking math and science subjects which improve spatial skills (Casey, 1996).

5.6. Experiment Three

Solid or Shaded 3D shapes.

In the third mental rotation task, participants were asked to look at 3D shapes via shutterglasses in the same way as they did for experiment two. In the first experiment, the shapes were similar to those used by Shepard and Metzler (1971) and later by Vandenburg and Kuse (1978). These were wire-framed shapes that gave the added bonus of perspective. The shapes in this experiment were the same as those in experiment two, except they were “solid” shapes and not transparent. The perspective cues were greatly diminished however shading was added to aid the perception of depth.

5.6.1 Shape From Shading

Shading was discussed in chapter three where it was explained that in order to extract shape from shading, the visual system uses prior knowledge, making the assumption that there is a single light source illuminating a scene and that this light source is shining from “above”. Such an assumption is based on retinal coordinates suggesting that the extraction of shape from shading is probably not cognitive in nature but rather it is extracted early in visual processing, before vestibular and cognitive correction for head tilt (Kleffner and Ramachandran, 1992). This means therefore, that with regards to shading, the visual system assumes that the sun, the major source of illumination, moves with the head.

Kleffner and Ramachandran explained that such a primitive assumption could be explained by the fact that although humans do tilt their heads from time to time, generally we walk upright. It is then possible for us to use heuristics in order to extract shape from shading without having to make time-consuming computations in order to correct for head tilt.

Of importance to this present research was Ramachandran’s (1988) study that focused on the way we perceive shape from shading. In an example of stereoscopic processing he showed an example of two pictures depicting a sphere, however, when they were “fused” together, as in using a stereoscopic viewer, the spheres vanish and the viewer sees a circular window cut into a rectangular sheet floating in front of a shaded plane. Ramachandran stated that extracting shape from shading is strongly affected by stereoscopic processing.

The shapes used in this experiment were viewed via shutterglasses that performed the same function as the stereoscopic viewer. If the shapes were viewed in 2D they were seen as two identical sets of shapes, side-by-side, different only in that they were similar to the points of view of two eyes. This is the same principle as used in 3D VR systems. When the 3D generated shapes were observed, displayed on a computer screen equipped with a 3D card and viewed via shutterglasses, each participant was asked if they perceived (using figure 5.8 as an example) the “L” shape of the left hand image being closer to them i.e. in the foreground, with the lower section receding into the background with a final section in the background protruding downwards, the same with the mirror image on the right hand side. This confirmed that the participants perceived the image in 3D.

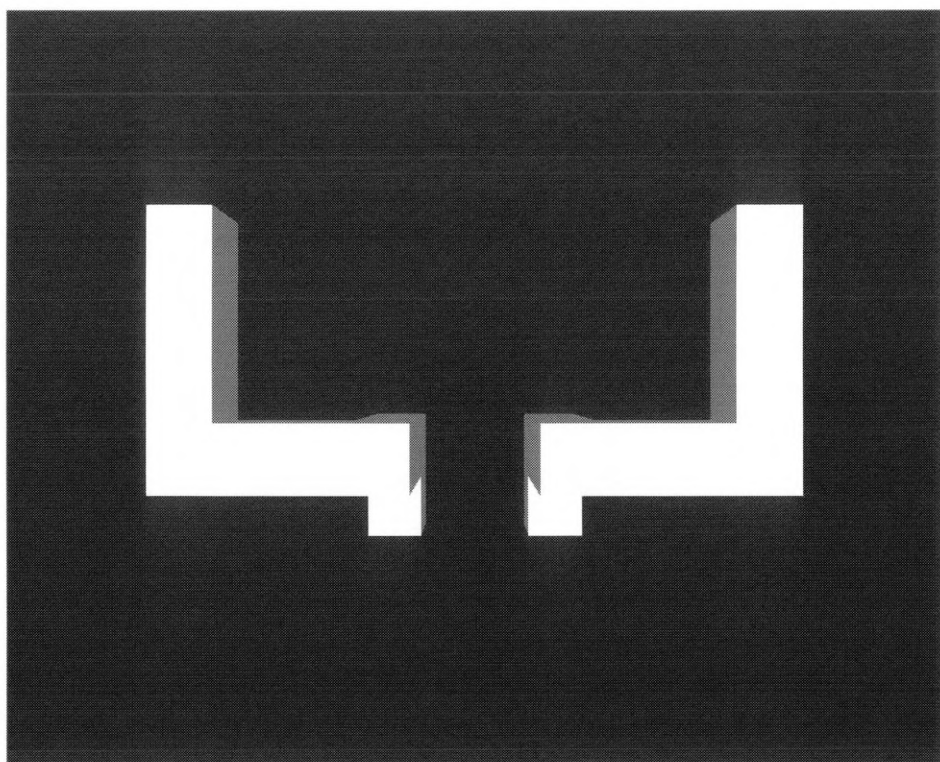


Fig. 5.8. Showing an example of a pair of “mirror-image “solid” shapes in the 3D “solid” mental rotation test. The shapes have been achieved by fusing together two identical pictures set slightly apart in order to create stereopsis if viewed in 3D.

As perspective was used as a depth cue in experiment two, shading was used to enhance depth cues in experiment three. The part shading plays in depth perception was discussed at some length in chapter three as it is necessary to understand its role not only to successful performance in the third mental rotation task but also to how we perceive depth when navigating real and virtual environments.

5.6.2 Experiment 3.

“Solid” Shape Test

The original S-M test used “wire-frame” shapes similar to those used in the previous “wire-frame” 3D test. In experiment three the wire-frame was removed and shading added to present “solid” versions of the shapes used in experiment two (see Fig.5.9.). The justification for this was that in life, whether real or virtual, humans rarely see objects as being transparent. The 3D wire-frames in themselves gave cues to depth and perspective therefore possibly making mental rotation easier for the participants taking part in the test and thereby revealing no gender differences. By removing the wire-frame, participants were possibly forced to make either more global or gestalt rotations of the objects or to use the more complex analytical processes to keep track of the shape as it was being mentally rotated. Keeping track of each part of the shape during the rotation may prove to be a more difficult task resulting in longer processing time and more mistakes (Shiina 1997). Being solid, as the shape is rotated, occlusion comes into effect, whereby parts of the shape disappear from view, thus mental rotation would be required in order to keep track of the shape rather than just looking through the shape as in the previous experiment.

In this present experiment, the test was again presented on a computer screen and viewed via shutterglasses, which created the illusion of depth. The comparison shapes were as before. As in the original test, drawings were avoided that contained singularities however by rotating the solid shape, some parts were occluded therefore making the shapes more complex than in experiment two.

Again, an extra element was added to the third test that was not present in the first. The participants were timed. They were not given a time restriction as such but were informed that speed and accuracy were being recorded along with the number of correct answers. The hypotheses, independent variables and dependent variables were as experiment two.

The Method

5.6.3. The design

As in Experiment two

Apparatus

As in experiment two. The shapes were exactly the same and presented in the same orientations and pairs. The only difference was that the shapes were solid and shaded.

Participants

Quota sampling was used to select the 69 participants, 31 males and 38 females, all were right handed and all were either students or academic staff whose discipline fell under one of two faculty headings i.e. Science and Engineering or Arts and Social Sciences. Forty-one were Arts of which 13 were male and 28 female, 28 were Science of which 18 were male and 10 female. A reward of £5

was paid to the students volunteering to take part in the test. All subjects had normal or corrected to normal stereovision and had not participated in the previous MRTs.

Procedure

As in experiment two

5.6.4 Results Section

Time Taken To Complete The Solid Shapes 3D Test.

The data was analysed and the results showed that the male and female performances in the “Solid” 3D Mental Rotation Test did not differ overall in the time taken to complete the test (means of 428.46s, S.D.=173.86s and 375.85s, S.D.=106.71s respectively.) The performance between the participants in the Arts and Social Sciences and those in the Science and Engineering Faculties differed with means of 362.91, S.D.=116.05 and 453.04, S.D.=161.19 respectively.

The time taken to complete the solid shape 3D test was analysed using a factorial analysis of variance with three between-participant factors of Gender (male and females) and Faculty (Arts and Social Sciences v, Science and Engineers). This analysis revealed that the main effect due to Gender ($F(1,61) = .726, p > 0.05, p = .39$) was not significant. For Faculty ($F(1,61) = 7.13, p < 0.05, p = .01$) there were significant differences showing that the Arts participants were significantly faster than the Science participants.

The interaction between Genders by Faculty ($F(1,61) = 4.42, P < 0.05, p = .044$) was significant. An analysis of variance (ANOVA) revealed that the significant differences lay between the Males in the Arts and Social Sciences and the Males

in the Science and Engineering Faculty $p < 0.05$, $p = 0.042$ (means of 351.08s, S.D. 144.21 and 484.35s, S.D. 175.42 respectively).

There was also a significant difference between the Females in the Arts and Social Sciences and the Males in the Science and Engineering Faculty $p < 0.05$, $p = 0.03$ (means of 368.41s, S.D. 102.99 and 484.35s, S.D. 175.42 respectively). This was graphically represented in Figure 5.9 and also showed that the Females in the Arts were faster at completing the test than those in the Sciences (means of 368.41s, S.D. 102.99 and 396.68s, S.D. 119.71 respectively).

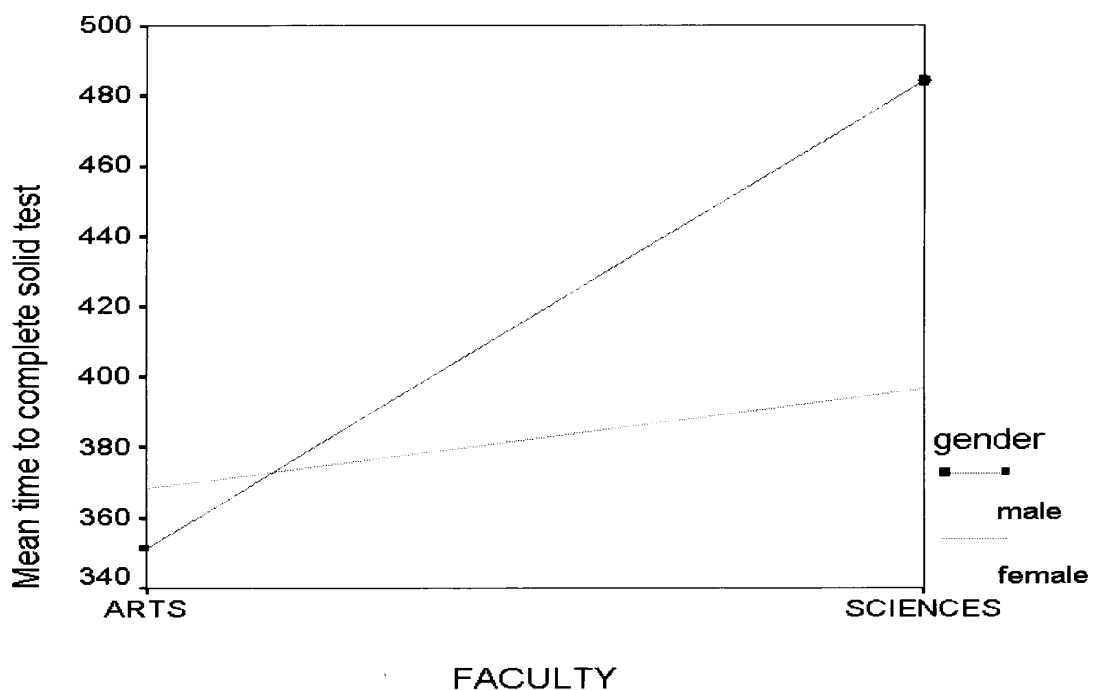


Figure 5.9. Graph showing the interaction between Gender and Faculty with regards to the time (in seconds) taken to complete the solid 3D test.

5.6.5: The Number Of Correct Answers In The Solid 3D Test

The data was analysed and the results showed that the Male and Female performance differed in their capacity to answer correctly with the Males scoring higher than the Females (means of 48.87, S.D.=6.46 and 44.63, S.D.=7.03 respectively). The means and standard deviations for Faculty were Arts 44.32, S.D.=7.23 and Science 49.79, S.D.=5.47 respectively

The number of correct answers were analysed using a factorial analysis of variance with three between-participant factors of Gender (male, females) and Faculty (Arts and Social Sciences, Science and Engineers). This analysis revealed a significant main effect of Gender ($F(1,61) = 4.58, p < 0.05, p = .036$) whereas for Faculty ($F(1,61) = 3.45, p > 0.05, p = .068$) there were no significant differences.

The interactions between Genders by Faculty ($F(1,61) = .085, p > 0.05, p = .77$) were not significant.

5.6.6 Discussion

With regards to the hypotheses, they were only partly supported. The first hypothesis was that the males would be faster and more accurate than the females. The males were in fact slower than the females however they were significantly more accurate than the females.

In the second hypothesis it was predicted that the Science faculty would be faster and more accurate. The Arts were in fact significantly faster than the Sciences and more specifically the Arts participants were significantly faster than the Male Science participants but not the Female Science participants. With regards to

accuracy there was no significant difference between the faculties, although the Sciences were more accurate than the Arts.

With regards to the time taken to complete the test, the finding by Voyer, Voyer and Bryden (1995) that putting time restrictions on tests hampers female performance did not apply in this case. The females were in fact faster than the males although not significantly. Voyer and Bryden (1990) also found that their female participants were faster than the males in their lateralised mental rotation test. They explained that, “such a sex difference may be due to a gender difference on speed in dealing with visually presented material...where females are generally superior to males.” Voyer, Voyer and Bryden did not have sex-related differences with regards to accuracy, however the males significantly outperformed the females on the 3D “solid” MRT, showing that there may have been a speed/accuracy trade off or more simply, the strategy females used to solve the “wire-frame” test was not good enough to solve the more complex “solid” test.

Although there was no main effect of faculty with regards to timing, the interaction between gender and faculty revealed a clearer picture. It was not just that the females were faster than the males but the male and female Art participants were significantly faster than the Male Science participants but not the female Science participants. This may indicate that the male Science participants were using a different strategy to solve the MRT, for example, analytical processing which may be slower but more accurate. The male Science participants were indeed the most accurate although not significantly so.

Of most interest, out of the three MRTs, it is the 3D “solid” test that has proven to be the most difficult, with regards to accuracy, for the females and has finally revealed the expected gender difference. One explanation may be that in the ROT, although not benefiting from 3D, there was a selection of visually presented alternative answers for the participants to choose from in order to answer the question. Mental rotation as such may not have taken place, but some other strategy such as looking for a particular component of the standard shape and searching for it on the rotated shape. One female did in fact comment that she tried to liken the shapes in the ROT to something familiar and gave a horse head as one example and then tried to find the horse head in one of the alternative answers. This is similar to Sherman’s observation (cited in Caplan and Caplan 1994) when testing participants on the EFT. She found a significant gender difference regarding the strategy for remembering the simple form to be disembedded. More females remembered the design by comparing it to a familiar object whereas males tended to hold a mental image of the design. In the “solid” test, the complex geometric shapes were transformed into familiar every day objects, therefore the presented shape was no longer a novel stimuli requiring analytical processing but instead analogue processing for familiar objects might have been used instead, as posited by Bodner (1989).

This however, does not answer why it was that gender differences, favouring males, are consistently found in the ROT unless of course, other factors had not been considered. The 3D “wire-frame” test, with not only the added bonus of the third dimension but also the transparency of the shapes and perspective, may have benefited everyone but especially those with poor spatial ability. However, in the

real world and in virtual worlds, scenes and objects are rarely transparent and are rarely seen as whole entities, invariably there will be parts occluded whether it be that the scene moves or the viewer does. The “solid” test was perhaps a more suitable test to use in a 3D environment as shading is an important depth cue that is vital for the perception of depth in a VE and the majority of shapes, used in the test, had areas that were occluded when rotated as would be found in both real and virtual worlds. The fact that females found this task more difficult, in that they performed significantly poorer with regards to accuracy, than their male colleagues, required further investigation in order to find out why.

5.7 Chapter Summary

Accuracy

The results as a whole are worth taking a close look at as they show, certainly in the ROT and 3D wire-frame tests, that as far as the gender of the participant was concerned, there was no significant difference regarding accuracy and no significant difference in reaction time in the wire-frame test. These results are contradictory to the expected and may indicate that the MRT, once a robust test of sex differences in spatial ability, has now gone the same way as other spatial tests whereby the differences are either negligible or non-existent. Alternatively, the results may indicate that factors other than the sex of the participant had a powerful role to play that had not as yet been considered.

Looking at the accuracy scores for the three mental rotation tests it can be seen that the hypothesis that the males would be more accurate than the females was not supported for the ROT or 3D wire-frame tests. Not only were the differences in each test not significant, they were almost identical. In the ROT the males

scored a mean of 13.87 and the females scored a mean of 13.11. In the wire-frame test the males scored a mean of 51.5 whereas the females scored a mean of 51.97. These are controversial findings, however work by Voyer and Bryden (1990), who were looking at the relationship between gender, level of spatial ability and lateralisation of mental rotation, also found no sex differences regarding accuracy in that particular study, so the findings in this present study are not unheard of.

In the ROT the expected male superiority was not produced. George Bodner (1997) stated, “males outscored females...the differences are not only statistically significant, they are reasonably large.” Sheryl Sorby (2000) found that the mean scores for women were significantly lower than the mean scores for men. In this present study there was no significant gender difference, in fact the difference was negligible. However, it has to be emphasised that Bodner and Sorby were only using students on either an introductory engineering graphics or chemistry course, which, in itself, may be factors that have to be controlled for. In other words, the entry qualifications for these institutions may be greater than the qualifications possessed by the participants taking part in this present study. This may therefore support Kimura (1992) and Benbow’s (1988) claims that there is a link between sex, spatial abilities and academic performance in subjects such as mathematics and physics etc.

It may be the case that greater spatial ability is reflected in the qualifications and grades needed for Chemistry and Engineering, qualifications such as the number of Mathematical subjects taken by the participant. If it is the case that the males

had the majority of the highest grades then this may explain their superior performance in Bodner and Sorby's results. The females, perhaps with lower mathematics grades, which are directly linked to their lesser spatial ability and skills, performed poorly in comparison to their male colleagues. On the other hand, spatial ability and grades in Engineering and Science may correlate for males but not for females. Such a hypothesis certainly warrants further research.

It is possible that the sample of participants used in this present study averaged at a more middle of the road range of abilities. It may be this factor that has produced no significant difference in accuracy between the males and females. In order to address this problem, testing in the third phase will take maths ability as well as faculty into account.

The 3D wire-frame MRT also produced surprising results. As stated previously, the Shepard and Metzler MRT, although never originally intended to measure sex differences, has consistently been shown to produce one of the largest and most reliable gender differences, favouring men, in the cognitive literature. However, in this present study no significant gender difference was found with regards to accuracy. Further there was no significant difference in accuracy with regards to Faculty. An explanation for this finding could have been found if the suggestion by Larson (1999) had held out. He suggested that females have a problem with three-dimensional visualisation. VR supplies the third dimension and females should therefore perform as well as their male colleagues. This, however, does not explain why the females performed as well as their male colleagues in the 2D MRT. Further research is required to ascertain if these results are replicable. If

the results are indeed replicated, as is the intention of further testing in this present study, then they cast doubt on the assumption that poorer spatial ability is at the route of the female problem within VR or at least the results will indicate that the present tests and procedures are now poor indicators of spatial ability with regards to sex differences. The results for the ROT and 3D MRT may indicate that, in line with several meta-analyses differences in spatial ability have indeed declined or disappeared, at least with regards to the standard mental rotation tests being administered

The solid 3D test however produced significant sex differences, with males scoring a mean of 48.47 and the females scoring a mean of 44.63, with an effect size $d = 0.63$, which is considered to be moderate to large. The solid test was more complex than the previous two, requiring the participant to mentally rotate a solid shape which had areas occluded from view. In the ROT the participant had some help in that a number of possibilities were already provided for the participant to choose from thereby aiding them in rotation and tracking. The wire-frame test provided cues in that the frames themselves were transparent and provided perspective. The Solid test, using shading as a depth cue, presumably required a great deal more cognitive processing and spatial ability thus revealing the expected difference, favouring males. Peters, Chisholm and Laeng (1995) made such an assertion when studying spatial ability, student gender and academic performance. They suggested that sex differences in spatial abilities might only occur for very complex spatial manipulations.

5.7.1 Response Rates

Interesting and indeed challenging results were found in the response rate of the participants. Again, contrary to the literature, the females were faster than their male colleagues at completing the wire-frame and solid tests, although it has to be emphasised that the differences were not significant. In the wire-frame test the females averaged a speed of 488.1 s whilst the males averaged 556.43s. For the “solid” test the females averaged 375.8s whereas the males averaged 428.46s. Quite why this should be is uncertain. Perhaps the timings reveal differing cognitive strategies. Perhaps the males used analytical processing whereas the females used a more gestalt or holistic form of processing resulting in the males taking longer but scoring more correct answers. However, it is also possible that the females were prepared to make more “gut felt” responses. This again is purely conjecture requiring further research although Voyer and Bryden (1990) explained the difference they found, favouring females, to females having greater perceptual speed.

However the results of the 3D tests deserves further enquiry, as a more focused research may reveal interesting cognitive strategies, which in themselves will be of use to educationalists. A further possibility to be considered is that the gender of the experimenter had an effect in that the males were wanting to create a good impression in front of their female experimenter therefore they took longer to make their decisions in order to get the answer correct. This was in fact the response of one male participant who said he did not want to look stupid in front of the female experimenter by getting too many incorrect. Experimenter effect is therefore a factor to be considered along with general anxiety and the effect it can

have on performance. Both are important factors and crucial to any experiment and the interpretation of the results.

5.7.2 Faculty

When interpreting the results concerning the Faculty to which the participants belonged, an interesting pattern was revealed. The ROT showed no significant difference between those participants in the Arts and those in the Sciences with regards to accuracy (mean of 12.55 and 14.18 respectively.) However, in the wire-frame test, a significant difference, favouring the Science and Engineering Faculty, was revealed with a quite large effect size of 0.73. That the Sciences should score higher would have been predicted by Kimura (1992) and Benbow (1988) as the Sciences require qualifications including mathematic based subjects where as the Arts do not, or rarely, require maths based subjects as an entrance qualification, depending on the university concerned. Such researchers correlate spatial ability with maths ability, therefore the results in this present test would not be surprising. However, the Science participants took longer than the Arts to complete the test therefore possibly indicating an analytical processing strategy, which takes longer than a more holistic style possibly favoured by the Arts who were moderately faster.

In the 3D “solid” test the Sciences were again slower than the Arts but with no significant difference in accuracy. Males however, were significantly more accurate than the females. These results are in complete contrast to the “wire-frame “test. It is difficult to find a possible explanation, however, findings from Casey (1996) may offer some guidance. Casey found that when testing “mathematically talented youth”, or “high ability-college bound ...students” or

“high school students in a math/science training programme” she found large gender differences on the Vandenburg MRT, favouring males. It was only when she tested “lower-ability high school college bound students” did she fail to find significant gender differences.

It might be that in the ROT, where there were no significant gender or faculty differences, the participants were generally of a “lower ability”. In the “wire-frame “ test where there was no significant gender difference but there was a significant faculty difference, the participants in the Science faculty were of a higher ability than the Arts participants. In the “solid” test, where the results were reversed, the males were generally of a higher ability than the females no matter the faculty they belonged to. It is therefore necessary to understand what constitutes higher and lower ability and to control accordingly.

A further finding of Casey’s was that mental rotation ability might be in part responsible for gender differences in math aptitude among high ability high school and college students. She stated that skill at using spatial thinking might well be the underlying mechanism for the pattern of relations between maths aptitude and mental rotation ability. High and low ability refers initially to maths ability, which is underpinned by the ability to use spatial strategies for problem solving. Effective mental rotation skills may be a marker for a general pre-disposition, which is the tendency to use spatial strategies for processing information.

The mixed bag of results found in the first phase of testing regarding mental rotation ability may be more due to maths ability than gender and faculty. Maths ability will therefore have to be taken into consideration in the third phase of testing. As these were independent design tests, different participants were used in each of the tests. Further testing should use a repeated measures design in order to control for differences such as maths ability.

5.8. To conclude

It can be seen from this assortment of results that more questions than answers were produced. The VR literature quite clearly points to gender differences in performance and these differences have often been explained by the females poorer spatial skills and mental rotation ability. Results to date, concerning this present study, give no such clear indications. It is clear that the gender or sex of the participant was not in itself enough to explain the differences in performance as was seen from the results of the three MRTs. Further testing would therefore look for a more precise explanation. The next phase of testing looked at environmental factors that may influence performance on mental rotation tests or indeed on any cognitive ability test. The factors to be considered were practice, motivation and self-perception.

In experimental phase three, a repeated measures design was used to ascertain if there was a correlation between the three mental rotation tasks with regards to speed and accuracy and to see if there was a correlation between MR performance and performance in a VR navigation task. Therefore the same participants used their spatial abilities/skills in a series of navigation, orientation and visualization tests, having first learned the layout of a virtual house. Questionnaires given to

the participants ascertained their maths ability; computer experience and time spent playing computer games. Answers from the questionnaires provided insight into other factors that had to be considered regarding spatial ability and performance within VR other than purely gender.

Chapter Six

Phase Two Experiments

Introduction:

This chapter is also devoted to mental rotation tests. As discussed in chapter two, mental rotation is an important component of visualisation and the ability to navigate the environment whether it is real or virtual. Males have consistently outperformed females in mental rotation tests and it has been argued that it is this ability, or lack of it, that explains why females do not perform as well as males in computer generated, virtual environments.

It has been argued, in chapter four, that the differences in spatial ability are biological. Certainly the evidence for these sex differences is overwhelming. Researchers such as Mary Czerwinski (chapter four) are looking at ways of minimising the effects of such sex differences by, for example, increasing the width of the screens used in VR, as females have a wider field of view than males.

The intention of this section is to look at the social or environmental factors that may influence performance with regards to spatial tests and ultimately VR. Gender differences will be manipulated by looking at factors that may influence a difference in performance that are more environmental than biological. The three factors to be considered in this current research are motivation, self-perception and practice. As discussed in chapter four, biological factors cannot be denied with regards to spatial ability and the male advantage, however the environmental factors cited as possible reasons for a female disadvantage cannot be ignored and will be tested in this present phase of experiments.

6.1 The Bent Twig

In the field of gender differences it has been the usual approach to compare the differences in performance between males and females, in other words to look at the main effects. In the first phase of mental rotation testing, main effects were looked at, along with interaction effects, in the way of Gender, Faculty and Age. In this second phase of experiments the effects of practice, motivation and self-perception will be manipulated to see if such environmental effects could go some way to explain differences in performance.

Sherman (1978) proposed a theory explaining how biological and environmental factors inter-relate in order to produce gender differences in spatial ability. Her “bent twig” theory suggests that boys in general have innate spatial interests, which are reflected in the type of toys, games, interests and eventual careers that they choose. They choose spatial toys such as carpentry sets and construction blocks, such as Lego, when made available to them and will play with them for many more hours than girls. Practice with such spatial activities develops their spatial abilities and this in turn widens the gulf in the initial differences in spatial ability found between girls and boys.

6.2 Testing phases

In this present phase the first test was to look at the effect of motivation on performance whereby the participants had the opportunity to take part in a competition where they had a chance to win £100. In the second test the ROT was used in the self-perception/stereotype experiment whereby participants in the experimental groups were either told males outperform females on MRTs or vice

versa, the control group were merely asked to complete the task. In the final practice experiment, participants did a paper and pencil version of the 3D “solid” test. The 60 stimuli test was divided into three, 20 stimuli tests. These were administered over a period of 7 days. As mental rotation tests and gender differences have been discussed in detail in previous chapters, the introduction to this phase of testing will concentrate on describing the environmental factors that may influence performance i.e. motivation, practice and stereotyping.

6.3 First Experiment: Motivation.

In the first experiment of phase two, motivation was manipulated by offering a financial incentive. A “prize” of £100 was the incentive or motivation for participants to perform at their maximum. Financial rewards are considered to be extrinsic motivations and may well appeal more to males (Chantel, Debrevia-Martinova and Vallerand 1996) and have a greater effect on their performance in the mental rotation test than females. However, having such an incentive may cause the task to have greater relevance or salience for the females, rather than just being some abstract task to perform. A control group was used whereby the participants were offered no incentive, as in phase one of the testing; this was to allow for comparisons between the groups. The hypotheses were that having an incentive would have a positive effect on performance with regards speed and accuracy for both the males and females. What is unknown is whether or not the incentive would reduce or eliminate any difference in performance between the males and females. Should the females perform as well as the males then motivation must be an important environmental factor to be considered with

regards to performance. In the control group, the standard male superiority, as evidenced by the literature, was to be expected.

Method:

6.3.1 Design

An experimental method and an independent groups design was used. The Independent Variables were the type of motivation given to the participant to complete the mental rotation test (with or without a £100 prize incentive) and Gender (male/female). The dependent variables were mental rotation ability i.e. the number of correct answers, and the time taken to complete the mental rotation test.

Participants.

Convenience sampling was used, as all 58 students recruited for the motivation test, were sixth year school pupils from Dundee High Schools taking “Higher” level psychology at Dundee College. Twenty-four were in the experimental group and 34 in the control group. Twenty-seven participants were male and 31 were female. They had a mean age of 17 years and two months. All were right handed and had normal or corrected to normal vision. They were not paid to take part other than the experimental group who had the incentive of possibly winning £100.

Apparatus.

As in experiment three, phase one.

Procedure

The participants were divided into males and females and then randomly into two groups. The control group class were given the same instructions as in experiment three, phase one experiments. In this experiment motivation was manipulated in that the control group was asked to perform the computer generated 3D “solid” MRT with no offer of a prize for the best performer. The experimental group were told that there was a prize of £100 to the person who was the fastest and most accurate. It was emphasised that the fastest or the most accurate person would not necessarily win the prize; it was a combination of both that was the winning factor. This was to ensure that the participants would not advantage one at the expense of the other. Money was offered as an incentive as it is an extrinsic motivational factor.

6.3.2 Results: Motivation test

Figure 6.1 shows a clear difference in the mean percentage of correct answers given in the motivation and no motivation conditions, showing a possible main effect of Motivation. In the No Motivation condition both the males and females performed better than those in the Motivation condition, although in the Motivation condition the females outperformed the males, with little overlap. In the No Motivation condition the males outperformed the females but with some overlap. The means and standard deviations are displayed in Table 6.1.

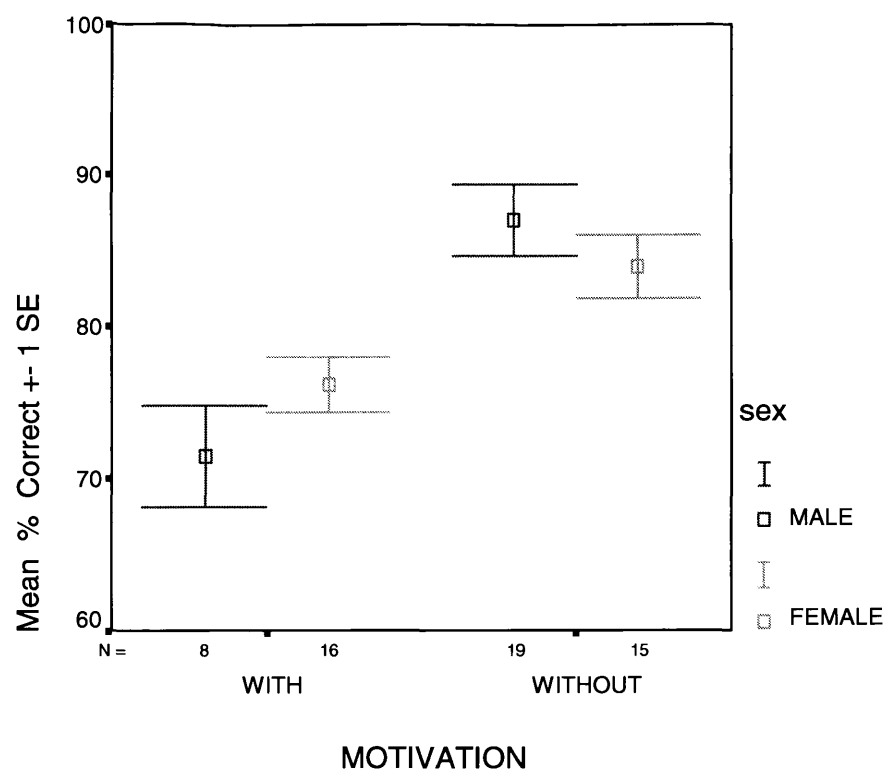


Fig 6.1 shows the mean percentage of correct answers given in the Solid 3D MRT for the With and Without Motivation conditions with two levels of gender, male and female.

	MOTIVATION			
	WITH		WITHOUT	
	Males	Females	Males	Females
% Correct Answers.	71.46	76.14	87.03	83.98
Standard Deviation	9.36	7.25	10.33	8.18

Table 6.1 shows the mean percentage of correct answers in the 3D solid MRT in the With and Without Motivation conditions with two levels of gender, male and female.

In order to analyse the data, an analysis of variance was used. There was a highly significant main effect of Motivation in that the group receiving no motivation significantly outperformed the group receiving a cash motivation $F(1,54)=22.65$, $p=0.0001$, $p<0.05$, $d=1.27$ (mean of 85.69 S.D.= 9.4 and 74.58, S.D.=8.12

respectively). There was no significant main effect of gender $F(1,54)=0.11$, $p=0.7$, $p<0.05$ (Male mean of 82.42, S.D.= 12.25 and Female mean of 79.93, S.D.= 8.56 respectively). There was no significant interaction between motivation and gender $F(1,54)=2.48$, $p=0.12$.

6.3.3 Time taken to complete the Motivation test.

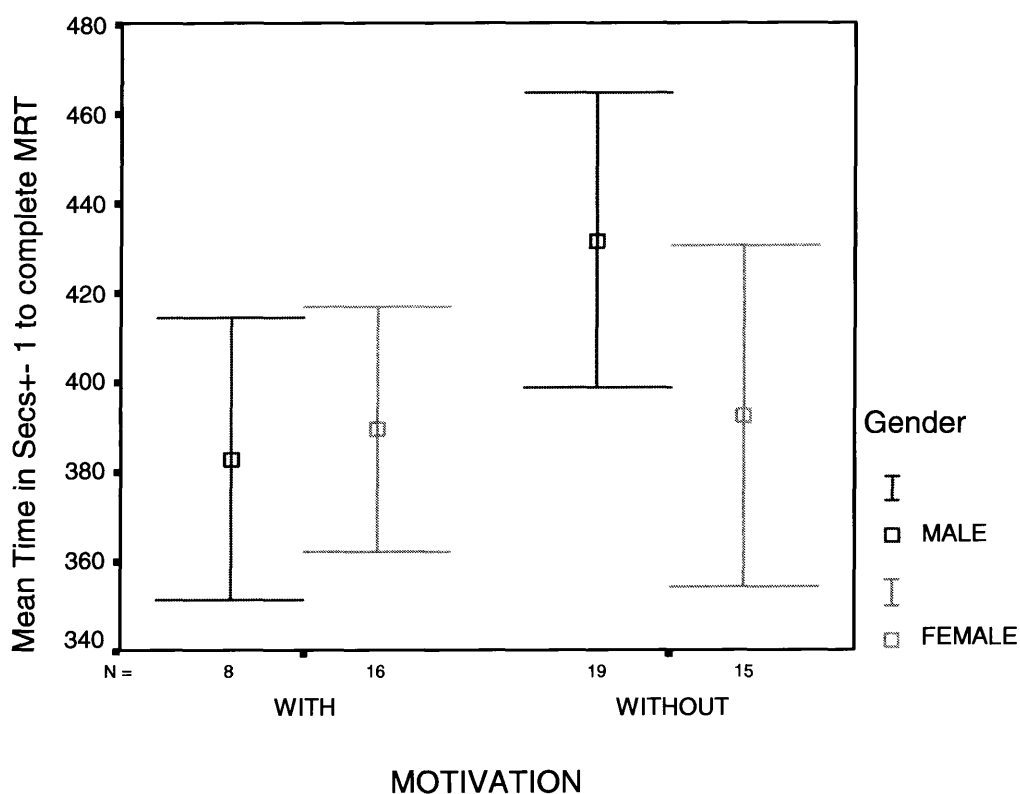


Fig 6.2 shows the mean time taken (in seconds.) to complete the 3D Solid MRT for the With and Without motivation conditions with two levels of Gender, male and female.

Figure 6.2 shows a difference in the time taken to complete the MRT in the motivation and no motivation conditions, showing a possible main effect of Motivation. There are considerable overlaps with regards to gender in both conditions with the females slightly slower in the With Motivation condition and

considerably faster in the Without Motivation condition. The means and standard deviations are displayed in Table 6.2

	MOTIVATION			
	WITH		WITHOUT	
	Males	Females	Males	Females
Time taken	382.61	389.14	431.46	392.22
Standard Deviation	88.99	109.66	144.14	147.8

Table 6.2 shows the mean time (in seconds) and standard deviations taken to complete the 3D MRT in the With and Without Motivation conditions for the two levels of Gender, male and female

In order to analyse the data analysis of variance was used. There was no significant main effect of Motivation with the No Motivation condition taking longer than the Motivation condition $F(1,54) = 0.52, p = 0.48, p > 0.05, d = 0.22$ (Mean of 414.14, S.D. 144.88 and 386.97, S.D. 101.31 respectively. There was no significant main effect of Gender $F(1,54) = 0.21, p = 0.65, p > 0.05$ (Male mean of 416.98, S.D. 130.51 and Female mean of 390.63, S.D. 127.32). There was no significant interaction between motivation and gender $F(1,54) = 0.4, p = 0.53, p > 0.05, d = 0.2$. (See table 6.2)

6.3.4 Discussion

From the results of the “ motivation” test, it could be clearly seen that the participants in the group that received **no** incentive to win performed significantly better with regards to accuracy than the group given the added motivation of a £100 prize and there was no significant gender difference in either group, which therefore does not support the hypothesis that the males would outperform the females in the control group. This was indeed a surprising result and may be

accounted for by a speed accuracy trade off or possibly, those participants in the experimental group may have been feeling more anxious about the test, however there were no significant differences in the time taken to complete the test with regards to gender or motivation. The motivated group were faster but made more mistakes whereas the control group took longer but made less mistakes. The motivation to win £100 may well have had a detrimental effect on their ability to perform. Participants in the experimental group may have made guesses or took short cuts in their processing strategies culminating in errors.

On the other hand, following Lepper's (1988) advice, the participants in the control group may have been intrinsically motivated. They carried out the task to the best of their ability because they enjoy doing tests or because they enjoyed challenging themselves. There was no competition involved so there was no rivalry with others with regards to performance therefore cutting down on any stress or anxiety, which may have been felt by the experimental group. Lepper (1988) stated that intrinsically motivated students use strategies that enable them to process information more deeply, using more logical information gathering than those students who are more extrinsically orientated. Lepper also said that extrinsic rewards could have the potential for decreasing existing intrinsic motivation. This may mean that the participants in the experimental group may have performed better if they had not been offered a cash incentive, however such a claim would require further investigation.

Eveland's (1998) general theory of information processing explained that influences such as motives and goals could affect learning, the level of attention

paid to content and the degree to which content is processed in a deep or elaborative manner. It is motivations and goals that controls learning in that they affect how much time are spent attending to the stimulus or elaborating on it using past experience or existing knowledge. The case of using a prize as an incentive meant that the participants were in competition with others. Although this may have been extrinsic motivation, the competitive aspect may have been the deciding factor. Participants were more interesting in winning than paying attention to the test resulting in a speed accuracy trade off; therefore motivation may not always be advantageous.

Interestingly there was no significant difference in the gender or gender by motivation conditions however the females in the experimental group did score higher than the males whereas in the control group, the males performed better than the females. This may be a clear indication that the right motivation can induce females to perform as well as their male counterparts in spatial tests. The fact that there was no significant difference in gender was contrary to findings in the first phase of testing where the 3D “solid” test showed a significant difference. One possible explanation is that in this test only psychology students were used whereas in the previous test a mixture of participants were recruited from the Arts and Social Science and Science and Engineering departments. As stated in the discussion section of chapter five, the participants in this phase of testing may have been lower ability students in that the very fact they were psychology students indicated a lower maths aptitude and consequently poorer spatial ability. (Casey, 1996). As both the male and female participants may have had poorer spatial ability from the outset, motivation would have had an equal effect on both.

Again maths ability may have been an important factor, which will be considered in phase three of testing.

6.4 Experiment Two

Practice Experiment:

Bodner (1989) concluded his paper by saying that practice can enhance spatial ability, making it a spatial skill that is learned, rather than being innate. It is this aspect that is of interest in the second phase of testing.

This present experiment followed the guidelines as laid out by Baenniger and Newcombe (1989) for training spatial skills. They advised that training has to be spatial in nature and that duration and content must be reported in detail. Duration can be long, medium or short. The definition of long is for the duration of a semester, medium is more than one administration lasting more than three weeks or is part of a curriculum that lasted less than one semester and short refers to a single or brief administrations lasting less than three weeks and is not part of a curriculum.

They also defined two types of training. Practice effects samples are repeated administrations of a sample spatial ability measure. Pre-test/post-test samples require two administrations of the same spatial ability measure sample. Training can also be general or specific with general focusing on a broad range of spatial abilities and specific focusing on a single area. If an improvement is found within task-specific training, then it shows that it is possible to directly train spatial skills.

This present study used a task-specific, practice effect sample style of training as it focused only on a single area, namely mental rotation. The mental rotation task had only a short duration as it consisted of three administrations space out over two weeks.

The test used was an adapted 2D, paper and pencil version of the 3D “solid” mental rotation test. The sixty-item test was divided into three tests, each containing 20 items. In the computer version of this test in phase one of testing, there was a gender difference, favouring males. Without the aid of shutterglasses and three-dimensionality, this test was more complex than the computer version. Forcing the participants to make a choice heightened complexity even further. They had to circle S, M or D depending on whether or not they thought the comparison shape was the same, different or mirror image of the standard shape (see appendix 2). This is more difficult as the participant has not only to decide if the shapes are the same or different, if deciding they are different they then have to decide if it is because they are entirely different shapes or because they are mirror images that prevents them from rotating the shape into congruence with the standard shape. The participants were not advised of their results after completing each 20-item test as this may have had an effect on their subsequent behaviour and results. Feedback may be an important issue to consider in future tests. The hypothesis was that practice would make a significant difference to performance for both the males and females.

6.4.1 Method

Design

The experimental method was used with a repeated measure design. The IV's were Gender (Male and Female) and the amount of practice they received (trial

1,2 and 3) and the DV was mental rotation ability i.e. the number of correct answers.

Participants.

Convenience sampling was used, as all 38 students recruited for the practice test were sixth year school pupils from Dundee High Schools taking “H” level psychology at Dundee College. There were 16 males and 21 females with a mean age of 17 years and one month. All were right handed and had normal or corrected to normal vision. They were not paid to take part in the experiment. The participants had not taken part in previous MRTs.

Apparatus

The sixty-item, 3D “solid” mental rotation test, as used in phase one of the experiments, was converted to three, 20-item paper and pencil tests (see appendix 2).

Procedure

The participants were tested in a class situation. They were given the 20-item test that had introductory pages explaining how to perform the test, along with sample questions. When the experimenter was certain that all the participants knew what to do; they were advised that they had five minutes in which to complete the test or as many as they were able in the time. After four minutes, the participants were advised that they had one minute left. The test comprised of twenty items whereby the participants had to decide if the comparison shape on the right was the same, different or a mirror image of the standard image on the left. To answer, the participants simply circled one of three boxes below the shapes. The boxes showed either an “S” for same, “D” for different or “M” for mirror image. For each correct answer they were awarded

one point. The participants sat the test at 1.30 on Test 1 (Thursday), Test 2 (Tuesday) and Test 3 (Thursday) as Tuesday and Thursday was the day they attended psychology class.

6.4.2 Results For Accuracy:

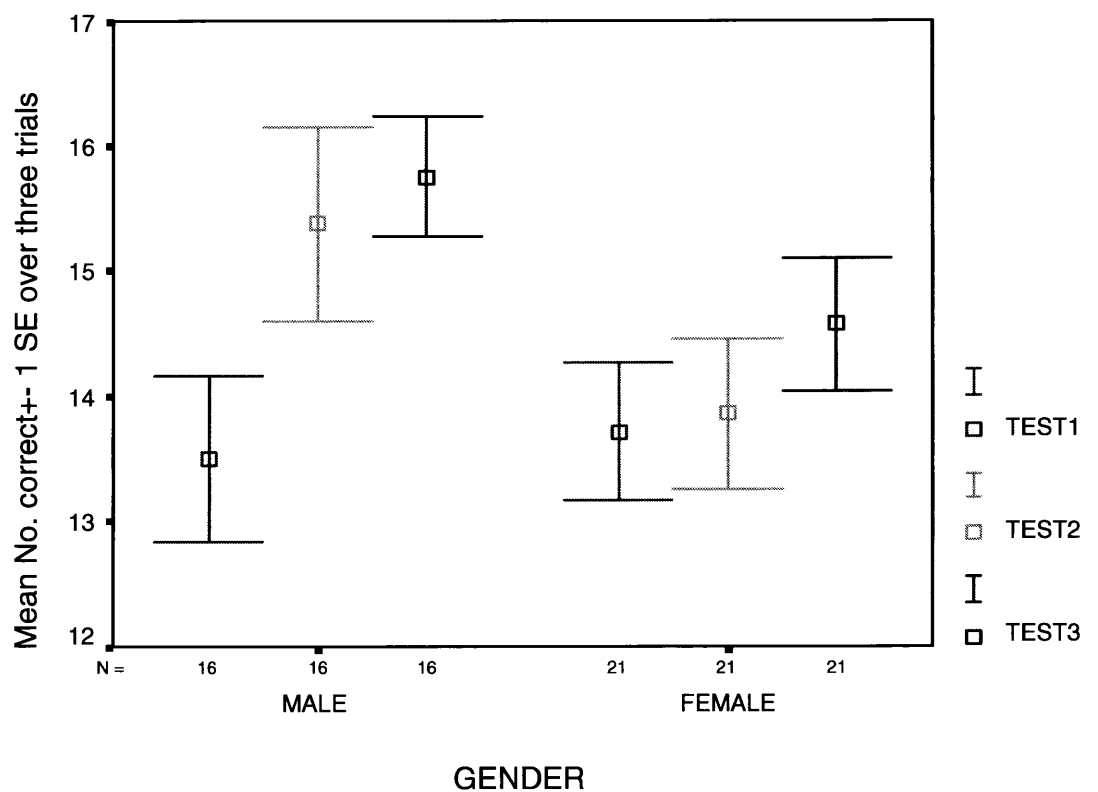


Fig.6.3 shows the mean number of correct answers in the 2D “Solid” MRT over the three tests for the Gender.

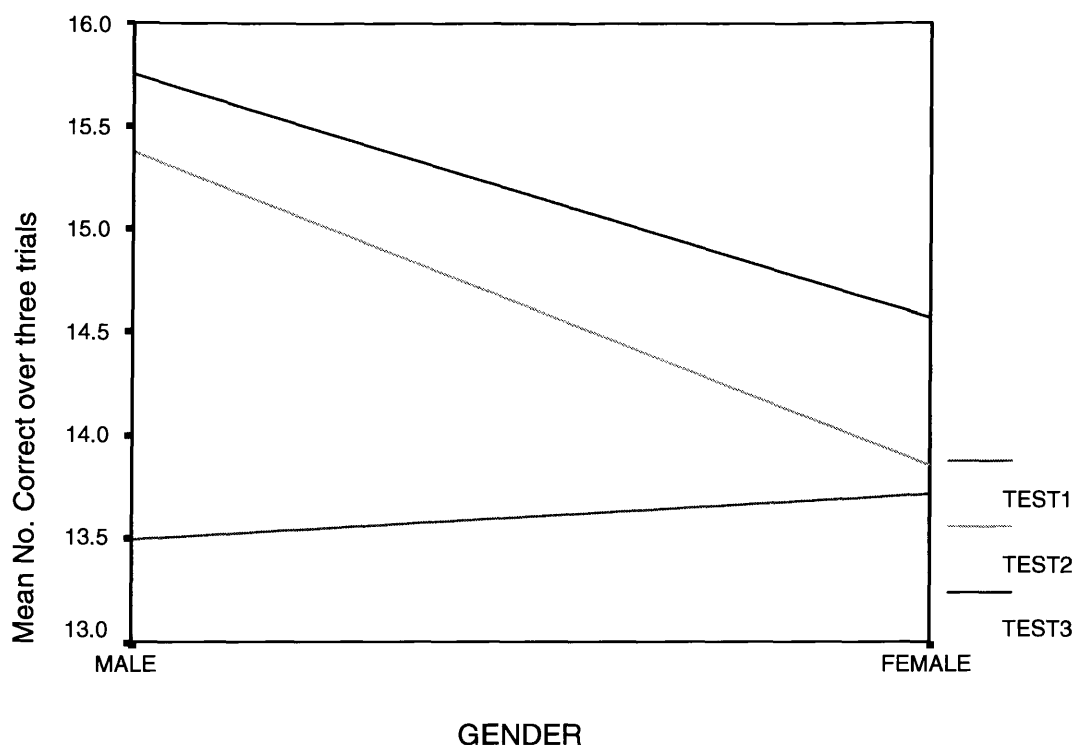


Fig.6.4. shows that practice over time had a greater effect on males than females.

Figure 6.3 shows considerable overlaps for the females on all three tests but only on tests two and three for the males. The graph gives no indication to interactions; however, it does clearly show improvement with practice. The means and standard deviations for the main effect of gender are displayed in Table. 6.3. Figure 6.4 shows that practice had a greater effect on the males than on the females especially between tests 1 and 2.

Condition		TEST 1	TEST2	TEST3
MALE	MEAN	13.50	15.38	15.75
	S.D.	(2.66)	(3.12)	(1.91)
FEMALE	MEAN	13.71	13.86	14.57
	S.D.	(2.51)	(2.74)	(2.44)

Table 6.3. Means and standard deviations for the number of correct answers given in the paper and pencil “Solid” mental rotation test, over the three tests for Gender.

In order to analyse the data a mixed analysis of variance was used. With regards to between subjects effects, there was no effect of Gender $F(1,35)=1.5$, $p=0.23$. There was no significant interaction between Tests or Gender $F(2,70)=1.99$, $p=0.14$, however there was a highly significant main effect of Test, $F(2,70)=5.88$, $p=0.004$.

Repeated sample t-tests, with Bonferroni adjustments for the number of comparisons, revealed no significant difference between tests 1 and 2, $t(36) = -1.68$, $p=0.1$, Mean 13.64 S.D. 2.54 and 14.51 and S.D. 2.97 respectively. There was no significant difference between tests 2 and 3, $t(36) = -1.35$, $p=0.19$, Mean 14.51 S.D. 2.97 and 15.08, S.D. 2.78 respectively. There was a significant difference between Test1 and Test3, $t(36) = -3.43$, $p= 0.002$, $d= 0.6$, Mean 13.6 S.D. 2.54 and 15.08 S.D. 2.28 respectively which shows that practice made a significant difference in the participants performance over the three tests.

6.4.3 Discussion

The results of the “practice” experiment showed a significant improvement between Test 1 and Test 3. These findings support the work of Turos and Ervin (2003) whereby they found significant improvements between trial one and trial four in their mental rotation tests. They however found that although both the males and females improved, the males were significantly more accurate over all of the trials. In this particular experiment there were no gender differences across the tests. This may well, once again, reflect the fact that all of the participants were psychology students and as such may have had poorer spatial ability, whether male or female, an issue to be addressed in phase three of the experiments.

According to Baenniger and Newcombe (1987), gender differences in their tests were eliminated when the participants were given specific instructions. In other words, when taken on a tour of a campus the participants were told to keep in mind the position of a specific building. The type and wording of the instruction was important and it was used as a guide to the kind of information that had to be attended to and stored for later retrieval. In this paper and pencil test there were clear instructions on how the participant should solve the problems, along with two trial questions. The clarity of the instruction may have relieved any anxiety or confusion which otherwise may have led to gender differences in performance.

Lohman and Nichols (1990) believe that improvement on spatial skills is largely task specific and that those with little practice on performing spatial skills will benefit most. Baenniger and Newcombe (1989) stated that females have more room for improvement than males. In this experiment there were no gender differences across the trials and as mentioned previously this may be explained by the fact that the participants were psychology students who, perhaps by default, have had little practice with spatial skills. Students of Science, Engineering, Architecture, Mathematics etc. will have much greater spatial practice due to the type of visualisation and problem solving they encounter on a daily basis whereas those favouring psychology may be more language orientated. Males with poorer spatial skills may be attracted to Arts type subjects for that very reason, hence showing no gender differences in performance in this test. It has to be noted however, that the males in this present test improved greatly between tests 1 and 2 and although initially poorer than the females in test one, were in fact better than the females by test 3 although not significantly so. This result is opposite to that

found by Baenniger and Newcombe 1989) suggesting that the choice or sample of participant taking part in spatial tasks is important with regards to environmental factors that might effect performance on spatial tasks other than the sex of the participant *per se*, such as prior experience or practice with spatial activities which will be considered in phase three of testing.

6.5 Experiment Three

Self-perception And The Mental Rotation Test

Mental rotation tests, as described by the literature still show robust gender differences favouring males. However, it has to be stated that the majority of recent studies were carried out in America and Canada. The Purdue ROT still consistently finds significant gender differences, favouring males, when used to ascertain spatial ability and potential academic performance in Chemistry and Engineering courses in universities in America. This same test will be used in this present study to see if such gender differences exist in a British university. To the authors knowledge, the Purdue ROT has not been used in the UK to measures students spacial ability although the test has been used in a number of American universities such as Carolina, Michigan, Lafayette, Purdue and Calawba College North Carolina.

If the gender difference persists then the difference could certainly be explained in terms of spatial ability and the biological/Nature argument for the differences can be accepted. Should it be that no gender difference is found, it could then be argued that there are cultural differences between America and the UK in that stereotypical gender roles are more blurred in the UK and have less effect on performance, therefore an Environmental/Nurture argument could be adopted.

As explained in chapter four, the way in which an individual perceives themselves will have an effect on how they perform. The consequences of inaccurate self-perception, in respect of this present research, are that negative self-evaluations may have damaging behavioural consequences. Perceptions of competence, or lack of, are tied to aspirations, preference for challenging tasks, curiosity, intrinsic motivation, persistence and task performance (Beyer, 1995; Elliott and Dweck, 1988; Cutrona, Cole, Colanero, Assouline and Russell, 1994).

In a navigation test, Kozlowski and Bryant (1977) found negative interrelations between a participants self-estimated spatial anxiety (worry about becoming lost) and their sense of direction and pointing accuracy. Higher ratings of spatial anxiety in females were also found by Bryant (1982) and Lawton (1994). Lawton's study found that spatial anxiety correlated negatively with performance in mental rotation and self-perception tasks, where males performed better than females. This therefore means that should participants in the ROT hold negative self-perceptions regarding their competence, this will be reflected in their performance.

In this present experiment self-perception was manipulated by giving males and females a "manufactured" belief about their sex's innate ability to perform spatial tasks, as described in the procedure section of the experiments design. If self-perception can influence task performance, then those participants believing they belong to the sex with the innate ability to do spatial tasks should therefore perform better than those who believe they do not have innate abilities. The hypothesis was that self-perception would have a direct effect on performance.

6.5.1 Self Perception Test

Method

Design

The experimental method was used with an independent groups design. The IV was the Gender of the participants (male/female) also the type of self-perception lecture received i.e. males have greater spatial ability or females have greater spatial ability, there was also a control group which received no pre-test lecture.

Apparatus

The ROT was administered as in Experiment one phase one.

Participants

Convenience sampling was used, as all 135 participants recruited for the self - perception test, comprised of sixth year school pupils from Dundee High Schools and college students taking “H” level psychology at Dundee College. There were 70 males and 65 females with a mean age of 22 years. In the “Boysbest” group, there were 26 males and 22 girls; in the “Girlsbest” group there were 22 males and 19 females and in the control group there were 22 males and 24 females. All were right handed and had normal or correct to normal vision. They were not paid to take part in the experiment. The participants had not taken part in previous MRTs.

Procedure

The participants were tested in their own classrooms therefore they had already been sub-divided into three at the beginning of the college year. The college students had been divided equally between the three classrooms so that there was an equal proportion of college to school students per class. The “Boysbest” group was given a short lecture by the experimenter on spatial ability, emphasising the

fact that males have historically outperformed females on spatial tasks, giving everyday examples such as map reading and parallel parking. The evolutionary theory for such differences was given as a means of explanation for such sex differences.

The “Girlsbest” group was given a lecture but on this occasion it was emphasised that females were better at spatial tasks, again using everyday examples such as threading needles and imaging furniture in different places in the house. Gender differences in performance were explained by explaining environmental differences in child rearing styles.

The lectures were used to influence the participants self-perception i.e. “I am a female (or male) therefore I should be good at this task” The control group received no pre-test lecture. The procedure was then the same as in experiment one phase one. For the “Girlsbest” group, after the test had been completed, it was explained that they had been deceived in order to influence their self-perception this was then followed by a brief lecture on the Evolutionary theory as given to the “Boysbest” group followed by a discussion on ethical issues such as deception, using the Milgram study (1963) into obedience as an example of extreme psychological testing.

6.5.2. Results For The Self-Perception ROT

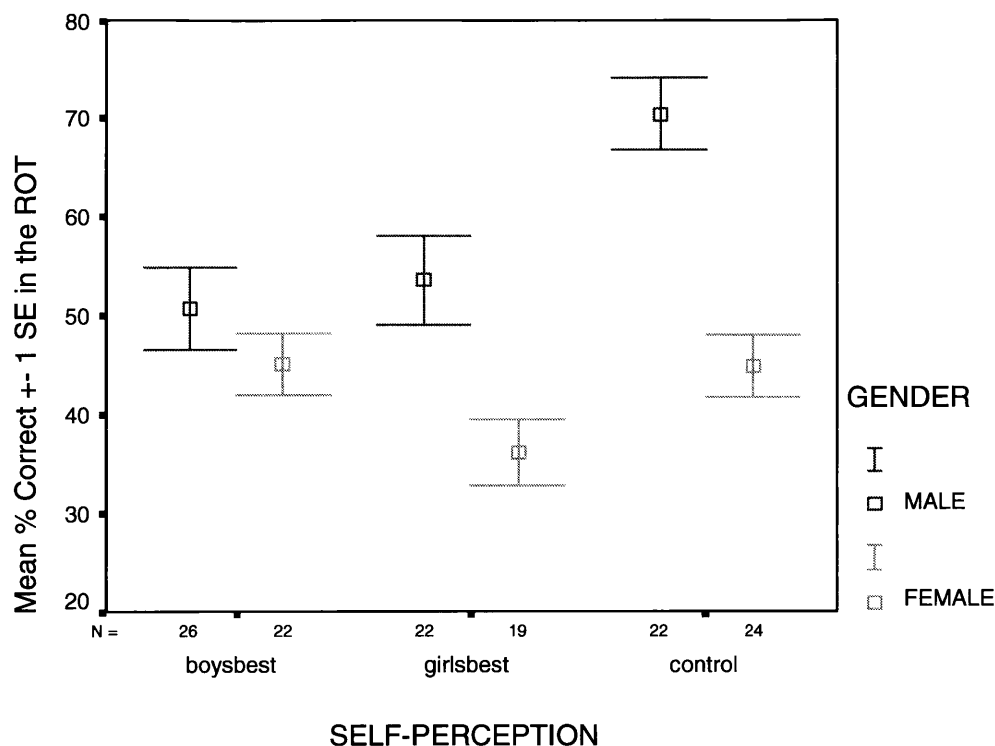


Figure 6.5. Graph illustrating mean percentage of correct answers (+1 S.E.) given in the ROT test for the self-perception conditions with two levels of Gender, male and female.

With regards to gender, figure 6.5 shows an overlap in the “Boysbest” condition but no overlap in the “Girlsbest” or “Control” conditions showing that there may be a main effect of gender and self-perception group, however this gives no indication to interactions. The males have outperformed the females in all three conditions. The means and standard deviations are displayed in Table 6.4.

Condition	BOYSBEST	GIRLSBEST	CONTROL
MALE MEAN	50.77	53.64	70.45
S.D.	21.57	21.05	17.25
FEMAL EMEAN	45.00	36.05	44.79
S.D.	14.64	14.58	15.29

Table 6.4. Means and standard deviations for the correct answers given in the ROT for gender by self-perception group.

To test the data further, answers given in the ROT in the self-perception test were analysed using an analysis of variance.

There were highly significant main effects for Gender $F(1,129) = 28.16$, $p = 0.000$, $p < 0.01$, $d = 0.84$ with the males outperforming the females. There was a highly significant main effect for self-perception group $F(2,129) = 6.24$, $p = 0.003$, $p < 0.01$. The means and standard deviations are displayed in Table 6.5. It can be seen from Table 6.5 that the males scored significantly higher than the females and that the “Control” group performed better than the “Girlsbest” and “Boysbest” experimental groups.

CONDITION	MEAN	STANDARD DEVIATION
PERCEPTION BOYSBEST	48.13	18.76
GIRLSBEST	45.49	20.18
CONTROL	57.07	20.64
GENDER MALES	57.86	21.66
FEMALES	42.31	15.18

Table 6.5 shows the means and standard deviations for the two main effects, self-perception group and gender.

Post Hoc Independent t-tests were performed (with Bonferroni adjustment for the number of comparisons carried out) on the self-perception condition and it was found that there was not a significant difference between the “Boysbest” and the

“Control” group, $t(92) = -2.2$, $p = 0.06$, $p > 0.05$. There was a significant difference between the “Girlsbest” and the “Control” group $t(85) = 2.64$, $p = 0.03$, $p < 0.05$, $d = 0.57$ in that the Control group performed significantly better than “Girlsbest” groups. There was no significant difference between the “Boysbest” and “Girlsbest” groups, $t(87) = 0.64$, $p = 0.53$, $p > 0.05$.

With regards to interactions, there was a significant interaction between self-perception and gender $F(1,129) = 3.69$, $p = 0.03$. Post Hoc Independent t-tests, (with Bonferroni adjustment for the number of comparisons) revealed:

1. A significant difference between the males in the Boysbest group and the males in the Control group $t(46) = -3.45$, $p = 0.006$, $p < 0.05$, $d = 1.01$
2. A significant difference between the males in the Girlsbest group and the males in the Control group $t(42) = -2.89$, $p = 0.003$, $p < 0.05$, $d = 0.88$.
3. No significant difference between the males in the Boysbest group and males in the Girlsbest group $t(46) = 0.46$, $p = 0.65$, $p > 0.05$
4. No significant difference between the females in the Boysbest group and females in the Girlsbest group $t(39) = 1.95$, $p = 0.06$, $p > 0.05$
5. No significant difference between the females in the Boysbest group and the females in the Control group $t(44) = 0.05$, $p = 0.96$, $p > 0.05$.
6. No significant difference between the females in the Girlsbest group and the females in the Control group $t(41) = -1.9$, $p = 0.07$, $p > 0.05$.

The males in the control group scored the highest; the females in the “Girlsbest” self-perception group scored the lowest. The means and standard deviations for the interaction, gender by self-perception group, are displayed in table 6.4.

Taking the tests separately, the performances of the males and females were compared using Independent t-tests. In the Boysbest group the males outperformed the females but not significantly so $t(46) = 1.06$, $p = 0.29$, $p > 0.05$. In the Girlsbest group the males significantly outperformed the females $t(39) = 3.06$, $p = 0.004$, $p < 0.05$, $d = 0.99$. In the Control group the males significantly outperformed the females $t(44) = 5.35$, $p = 0.000$, $p < 0.01$, $d = 0.99$.

6.5.3. Discussion

The results of the self-perception experiment are intriguing in that the males performed significantly more accurately than did the females, contrary to findings in experiment one, phase one, however the results were more complex than that.

The hypothesis was supported in that self-perception did have a significant effect on performance but not in the way the author assumed. Rather than improving performance, informing the female participants that they were better at spatial tasks than males, appeared to have a negative effect on their performance. This may indicate that how the participants viewed themselves may have had an effect on their performances. The males in the control group who received no pre-test lecture with regards to which gender was better at mental rotation tests, produced the highest mean score. What is interesting is that they also did significantly better than the males in the group where the boys were told that they were better than girls at mental rotation tests. It could be read that the males in the “Control” group simply performed to the best of their ability without the external pressure of being told how they should perform. The males in the “Boysbest” group felt under pressure to perform not only in comparison to the females but also in comparison to their fellow males, although they performed better than the females

they did not perform as well as the Control group males. In the Girlsbest group the males also outperformed the girls, this could be put down to competition in that males enjoy competitive games as discussed in relation to preferences with regards to computer games. Being told that the females were better created a challenge that the males rose to. Of course, the results could merely support the understanding that males generally have better spatial ability than females but that self-perception does have an impact in both decreasing and increasing performance. As Beyer (1990 and 1977) suggested, negative self-evaluations may have damaging behavioural consequences. Elliot and Dweck (1988) agreed by saying perceptions of competence are linked to intrinsic motivations, persistence and performance.

Females in the group that were told females were better at mental rotation tests could also have “suffered” from the above explanation. The fact that they performed the worst out of all the possible combinations may indicate that negative self-evaluation did indeed have an effect on their performance. A number of the female participants in the “Girlsbest” experimental group did in fact make comments after the test stating that being told they were better made them feel “stressed” and “anxious” as they knew they were not good at spatial tasks. Previous experience, coupled with the information that they should be better than the males, had a negative effect on their performance, whereas in the Control and Boysbest group where there was no pressure to perform well, the females scored similarly. As Nicholl stated, females blame themselves for failure in tasks and attributing failure to a particular task will determine their success in subsequent tasks.

Although this experiment did reveal significant gender differences, supporting the American studies, it cannot be ruled out that some of the differences could be explained by environmental factors such as self-perception and whether or not participants viewed themselves as fitting into a particular stereotype. A further consideration was that math ability, linked with spatial ability (Kimura, 1992, Benbow and Stanley, 1983) and previous experience had not been taken into consideration and it might be that such variables had an effect on individual performances. In phase three of testing such considerations will be dealt with.

6.6. Chapter Summary

Altogether, the three tests have given a mixed bag of results giving some support to the notion that environmental influences may have an effect on how individuals perform on a spatial task such as mental rotation. The motivation test, using a computerised 3D “solid” shape MRT, instead of showing a marked improvement in performance, in fact showed that offering a “prize” had a negative effect on the participants. By adding a competitive edge to the task may have detracted from attention and problem solving strategies, instead guesses or gut-feelings may have been substituted for the sake of time. Despite the prize and timing factor, there were no significant gender differences in performances.

In the “practice” experiment, using a paper and pencil version of the 3D “solid” shape MRT, there was also no gender difference, perhaps indicating that the type of subject the participants were taking i.e. psychology, is one that does not require excellence in spatial skills therefore males with poorer spatial ability and less practice in spatial activities, are attracted to such subjects. This then might explain why no gender differences were found.

What is of importance to this present study is that everyone, males and females, improved significantly between trial one and trial three. This however does not mean necessarily that spatial ability improved generally but it certainly improved on this specific task, therefore lack of practice or experience may explain the gender differences usually found in MRTs. Interestingly, although both males and females improved over time, the male performance increased substantially between the first and second test showing that initially they benefited more from practice. By the third test, although there was no significant gender difference in scores, the males had gone from being the poorer performers in test one to the better performers in test three. This result is worthy of further exploration in order to fully understand the benefits of practice on both males and females with poor spatial skills. Lack of practice can be considered an environmental factor although an evolutionary reason for the lack of practice in spatial skills could equally be employed, again indicating the difficulty in disentangling the nature/nurture debate, if indeed it is possible to disentangle.

It has to be remembered that the computer generated, 3D "solid" mental rotation test used in phase one of testing (chapter five) showed significant gender differences. Carrying out the same test but in 2D may have been even more complex and too challenging for both the males and females, who were all psychology students, indicating that task complexity produces no gender differences at the lower end of spatial ability scale assuming that maths ability and spatial ability are related.

The self-perception test, using the paper and pencil ROT, did show a gender difference as would have been predicted by the literature. The surprising result was that the control group males outperformed everyone else, even the males in the group who were told males were better than females at MRTs. Environmental factors such as culture have a great influence on how individuals view themselves but in this case past experience and negative self-evaluations may have had a stronger effect on participants than seeing themselves stereotyped into particular gender roles. Interestingly, in the first phase of testing the ROT produced no gender differences suggesting that something other than sex differences influences performance.

An important consideration is that the tests were carried out by different groups of people who may have had other experiences that might have affected their performance such as previous computer experience, mathematics ability or the amount of time they spend playing computer/video games. These variables will be considered in the next phase of experiments. The tests were also very different in style; the ROT is said to use more Gestalt or holistic processing whereas the computerised 3D MRT uses Analytic processing ((Bodner, 1987). For the final phase of the experiments all of the participants will undertake the three mental rotation tests that involve both types of processing in order to see if there is a correlation between performances. Importantly, the same participants will take part in the exploration of a VE and their performance on navigation tasks will be correlated with their performances on the MRT to see if there is a relationship between the two and to clarify if it is poorer mental rotation ability that underlies poorer performance with VR.

Chapter Seven

Phase Three Experiments

Introduction

Chapter one gave evidence of gender differences in performance within virtual reality. The differences were found in presence ratings (Winn, Hoffman, Hollander, Osberg and Rose, 1977), comprehension of science (Osberg, Winn, Rose, Hollander and Hoffman, 1997), awareness of the physical world whilst immersed (Byrne (1993), mental rotation (Buckwalter *et al* 1999), transference of knowledge from a virtual to real world (Waller, Hunt and Knapp 1998), simulator sickness (Kennedy, Lanham, Massey and Drexler 1995), navigation strategies (Czerwinski, Tan and Robertson 2002), place learning ability (Astur, Ortiz and Sutherland (1998) and spatial knowledge (Waller, Knapp and Hunt 1998).

Research into VR has suggested that gender differences in performance within VR are due to females having poorer spatial ability, particularly the ability to mentally rotate objects in their “minds eye” and that it is this ability which underpins the ability to navigate successfully, both a three-dimensional computer generated world and the real world. In this present research MRTs were used to measure mental rotation ability as these have been shown to consistently produce robust gender differences whilst other measures of spatial ability are now tending to show no gender differences or differences that are negligible (Voyer, Voyer and Bryden, 1995, McIntyre 1997, Caplan and Tobin, 1985)

7.1 Previous phases of testing

The previous two phases of testing queried the finding that females are poorer at mental rotation tests. Of the six MRTs only two showed a significant gender

difference, favouring males, with regards to accuracy. The first was the “Solid” 3D MRT using both Arts and Science participants. In the second phase of testing, using participants who were all psychology students, the same “Solid” test but in a 2D, paper and pencil format, revealed no gender difference but did show that offering a reward of a £100 prize may have had a negative effect on the participants performance. It was possible that having a sample of only psychology students may have had an effect on performance in that both the males and the females had poor or at least equal spatial ability and that the complexity of the test was a challenge for both the males and females equally.

The second test to show a gender difference, favouring males, was the 2D ROT where self-perception was manipulated. Overall the males performed better than the females but it was interesting to note that the control group performed better than the two experimental groups. Being “told” that you are supposed to be good at a particular task might have had a detrimental effect on performance, with a number of females in the “Girlsbest” group stating that they felt anxious when expected to do well at the mental rotation test.

Altogether there was an assortment of results with phase two experiments showing that environmental influences have to be considered when discussing differences in spatial ability. The sex of the participant did not necessarily predict their performance and practice did indeed enhance the performance of those individuals with poorer spatial ability. The motivation and self-perception tests showed decreases in performance. Both factors are environmental and as such, these findings are important for educational and training purposes, as the correct

manipulation should increase performances, particularly with regards to VR in this instance.

7.2 Phase Three

With regards to females poorer performance in VR, it was not enough to say that the difference was due to innate biological differences as the two previous phases of experiments showed no sex differences in four of the six mental rotation tests. In this final phase of experiments the relationship between mental rotation ability and performance within VR was explored. The 2D paper and pencil ROT, 3D “wire-frame” and 3D “solid” computer generated tests were used once again. Participants who had not taken part in the previous MRTs were recruited and asked to complete all three tests and their performances compared to see if there was a positive correlation between performances.

The justification for the correlations was that Bodner (1989) stated the 2D ROT was solved using Gestalt or holistic processing whilst the Shepard and Metzler MRTs were solved using analytical processing, of which the 3D “wire-frame” test is a version whilst the 3D “solid” test could be considered a hybrid of the two. If Bodner was correct, there should be a positive correlation between the “solid” and “wire-frame” tests or between the “solid” and ROT test but not between the three tests, giving some indication as to which type of processing was used to solve the 3D “solid” test. The resultant findings could be used to provide an indication to the form of processing used in everyday mental rotation problem solving such as navigating a three dimensional world. The “solid” shapes are more true to real life than shapes that are transparent as found in the “wire-frame” test and it is highly unlikely that we perceive objects with alternative versions in different orientations

close by. Seeing an object and perceiving its shape from shadows is an every day occurrence.

Performance on the MRTs was correlated with the participants performances in a virtual environment. The aim was to see if MRT performance correlated with any of the aspects tested in the virtual environment i.e. route and layout recall, orientation and visualisation, all of which required spatial aptitude for successful performance. Mental rotation could be argued as being a necessary strategy for solving all of the tests questions as the participants had to remain orientated in order to travel throughout the environment as per instructions but also in order to visualise the environment when answering the paper and pencil based tests. Mental rotation and orientation are particularly important when interacting with a VE because in the real world a person can generally move around any object that is to be viewed but in a synthetic world the object has to be moved in such a way as to create the illusion that it is the person who is moving around the object. To do this successfully the user of the VR system has to learn a new way of viewing objects which in itself requires the learning of new operational skills for using the interactive devices such as mouse, keyboard, joystick and in more sophisticated systems, the use of helmet and data gloves.

Importantly, it was of interest to see if gender or sex differences occurred in any or all of the tests and not only was the sex of the participants taken into consideration but also their age and faculty. A questionnaire ascertained the participants computer experience, maths ability and the length of time the

participants spent playing computer games, as these are all influences that could have had an effect on performance in both the mental rotation and VR tests.

Chapter three has already explained how it is we perceive space in natural environments. The ability to recognise objects and judge distances in depth was discussed, as was motion perception, which is vital for navigation. Navigational awareness was defined as having a complete navigational knowledge of an environment (Satalich, 2000) and studies showed that the construction of cognitive maps built during navigation of a virtual environment was comparable to those constructed in a real environment. (Witmer, Bailey and Knerr, 1996)

Chapter three also looked at navigation strategies and geographic knowledge and it was found that males know more about world geography and that males and females differ in navigation strategy, with males using miles and cardinal directions and females using landmarks and left right directions (Dabbs, Chang, Strong and Milun (1998). It was also found that when learning routes, males made fewer mistakes, used their knowledge of Euclidean properties and took fewer trials to find their way to a given target whereas females tended to use landmarks in order to aid navigation (Galea and Kimura 1993) and Miller and Santoni 1986).

It was explained that there might be an evolutionary explanation for such differences (Eals and Silverman, 1994) in that females, in their role as “gatherers”, evolved small-scale spatial memory abilities and developed relevant representations of space i.e. relative positions, where as males, in their role as

hunters, evolved greater spatial ability than females. Their success as a hunter depended on accurate large-scale navigation abilities, in that they had to be able to explore novel environments, keep track of orientation on long distance trips and be able to develop relevant representations of space i.e. directions and distances. It is these very differences that were tested in the navigation test. Spatial ability was tested using the mental rotation tests and navigation ability was tested in the virtual environment.

7.3 Mental Rotation Tests

The Method

Design

An experimental approach was used. The ROT, as before, was a timed test with participants allocated 10 minutes to complete the test. It was also a twenty-item, paper and pencil, 2D test. The two 3D MRTs were computer generated and viewed via shutterglasses giving the impression of depth. They both were sixty-item tests and participants were not given a fixed time within which they should aim to complete the tests. The differences in dimensionality, item number and timing instructions between the ROT and 3D MRTs meant that the ROT was treated as an independent measures design and the 3D tests were treated as repeated measures. In order for correlations to be made between the tests, the percentage of correct answers was used for data analysis. The 2D ROT was the same as in previous tests.

For the 3D repeated measures test there was a further Independent Variable. The IV's were the type of mental rotation tests (3D wire-frame and 3D solid MRTs) Gender (male/female) and Faculty (Arts and Social Sciences and Science). The

Dependent Variable was spatial ability i.e. the percentage of correct answers scored. The percentage of correct answers rather than the number of correct answers was used in order to make it possible to ascertain whether or not there was a correlation between the performances on all three tests (the ROT is a twenty-item test whereas the 3D tests have 60 items). Time was also a Dependent Variable i.e. the time taken to complete the tests.

Apparatus

The apparatus required for ROT and 3D MRTs were described previously. A questionnaire was completed by the participants regarding their sex, age, mathematics ability, computer experience and the number of hours they spent playing computer/video games. (See appendix 3)

Participants

Quota sampling was used to select 57 participants, 29 males and 28 females, all were right handed and all were either students or academic staff whose discipline fell under one of two faculty headings i.e. Science and Engineering or Arts and Social Sciences. Thirty-one were Arts and 26 were Science. Twenty-seven was the mean age of the participants. A payment of £10 was given to the participants who volunteered to take part in the test. All participants had normal or corrected to normal vision.

Procedure.

The participants were tested individually with 10 minute refreshment breaks between the tests. The tests were counterbalanced in order to avoid practice effects and indeed boredom effects. The participants were requested to complete

a questionnaire (see appendix 3) before testing began. The procedure for the tests was as before.

7.3.1 Results for the Mental Rotation Tests:

ROT: Percentage Of Correct Answers.

	GENDER		FACULTY	
	Males	Females	Arts	Science
% Correct	68.10	62.32	56.29	75.96
Answers.				
Standard	21.44	23.71	22.73	17.38
Deviation				

Table 7.1 shows the mean percentage of correct answers in the ROT in the two conditions gender and faculty.

Table 7.1 shows the mean percentage of correct answers plus standard deviations for the two Independent Variables Gender, Faculty. The results show that the males were more accurate than the females and the Science and Engineering participants were more accurate than the Arts and Social Science participants.

To test these observable differences, the percentage of correct answers was analysed using a factorial analysis of variance with two between participant factors of Gender (male and females) and Faculty (Arts and Social Sciences, Science and Engineers. There was no significant main effect of Gender $F(1,49) = 0.002$, $p = .96$, $p > 0.05$. There was a highly significant main effect of Faculty $F(1,49) = 9.74$, $p = 0.003$, $p < 0.01$, with the Science participants answering significantly more correct than the Arts participants.

With regards to interactions, there were no significant interactions between Gender and Faculty $F(1,49) = 1.59, p = 0.21, p > 0.05$.

7.3.2 Results For The Wire-frame and Solid Tests: Accuracy:

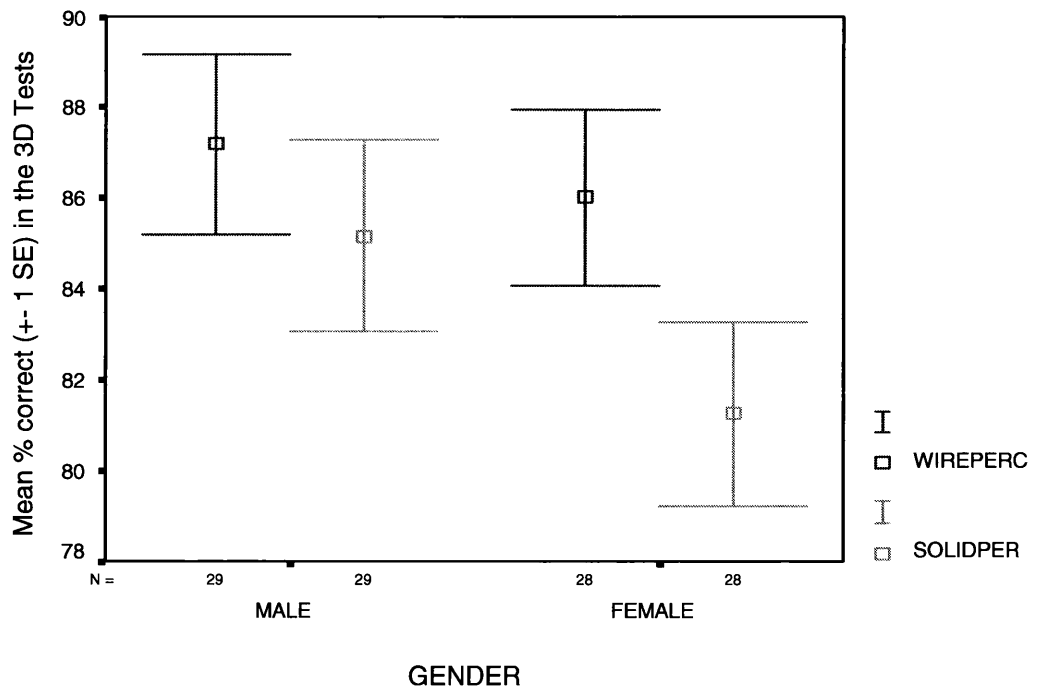


Figure 7.1. Graph showing the percentage of correct answers (+1 S.E.) according to Gender, in the wire-frame and solid 3D mental rotation tests.

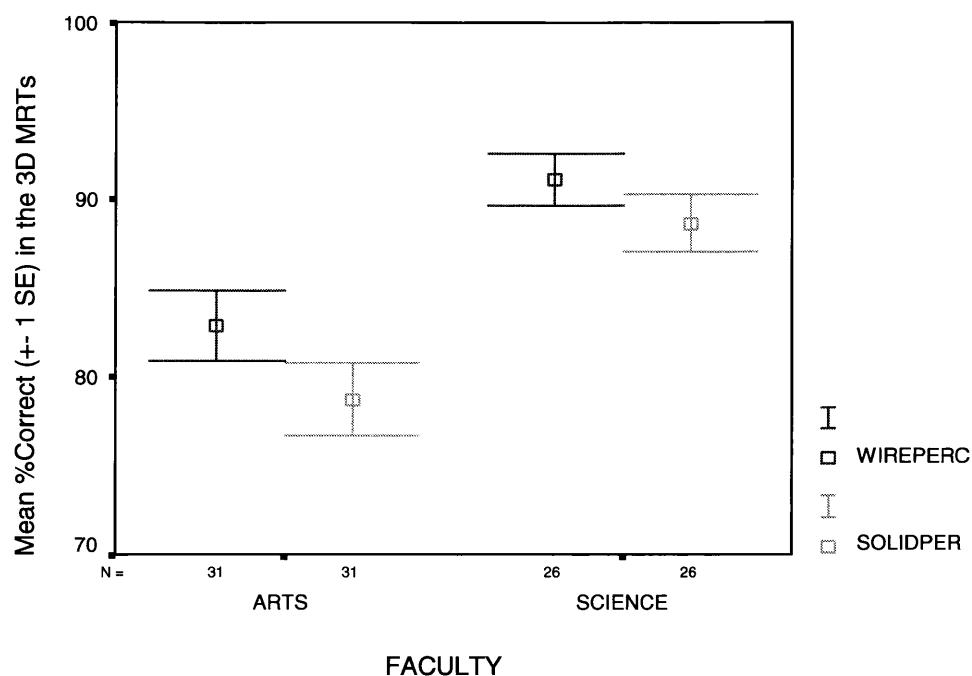


Figure 7.2. graph showing the percentage of correct answers (+1 S.E.) according to Faculty, in the wire-frame and solid 3D mental rotation tests.

	GENDER		FACULTY	
	Males	Females	Arts	Science
Wire-frame	87.18	86.01	82.85	91.09
S.D.	10.63	10.37	11.17	7.42
Solid	85.17	81.28	78.71	88.65
S.D.	11.37	10.68	11.19	8.41

Table 7.2 shows the mean percentage of correct answers and standard deviations for the wire-frame and solid tests with regards to Gender and Faculty.

In Figure 7.1 it can be seen that the wire-frame test was easier than the solid for both males and females and that the females were much poorer at the solid test

than the males. Figure 7.2 shows that again the wire-frame test was easier whilst the Science participants performed much better than the Arts in both tests indicating a possible main effect of Faculty.

In order to analyse the data a mixed analysis of variance was used. There was no significant within subject effects for type of Test ($F(1,49) = 3.16, p = 0.82$, Test by Faculty $F(1,49) = 3.25, p = 0.78$, Test by Gender by Faculty $F(1,49) = 0.23, p = 0.63$,

With regards to between subjects effects there was no significant effect of Gender ($F(1, 49) = 0.11, p = 0.75$). There was a highly significant effect of Faculty $F(1,49) = 15.24, P = 0.00, p < 0.01$ with the Science participants answering significantly more correctly than the Arts participants, as shown in means Table 7.2

There were significant interactions between Gender by Faculty ($F(1,49) = 5.9, p = 0.02$).

Post Hoc Independent t-tests, with adjustments for the number of comparisons, revealed that the males in the Sciences scored a significantly higher percentage of correct answers than their male colleagues in the Arts i.e. Wire-frame test = ($t(27) = -3.41, p = 0.002, p < 0.01, d = 1.34$) and Solid test = ($t(27) = -3.81, p = 0.001, p < 0.01, d = 0.71$). There was no significant difference between the scores in the two conditions for females.

7.3.3 Time Taken To Complete The 3D Mental Rotation Tasks

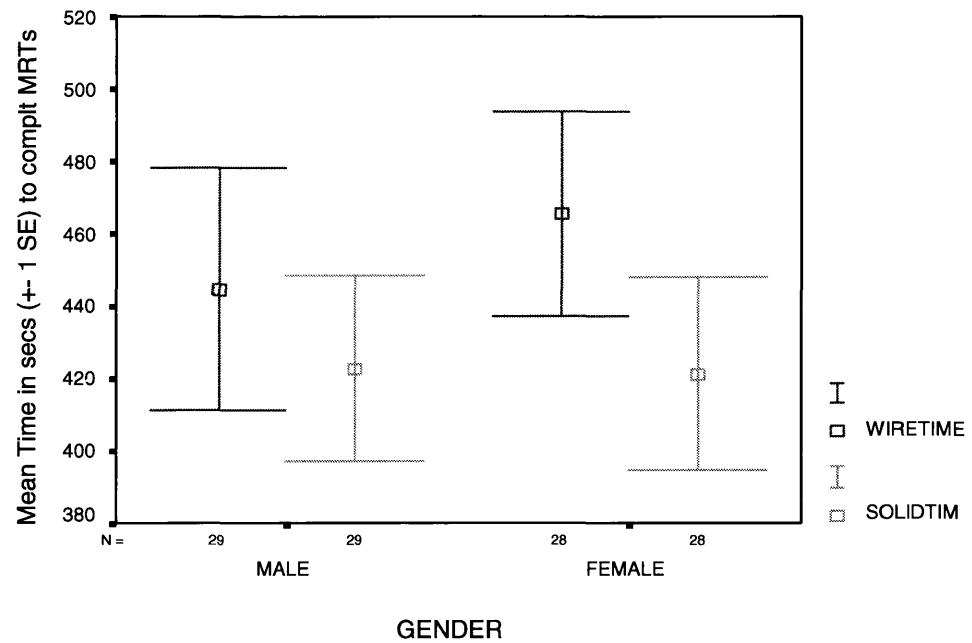


Fig.7.3. Shows the mean time, in seconds (± 1 S.E.) to complete the Wire-frame and Solid MRTs for Gender, Male and Female.

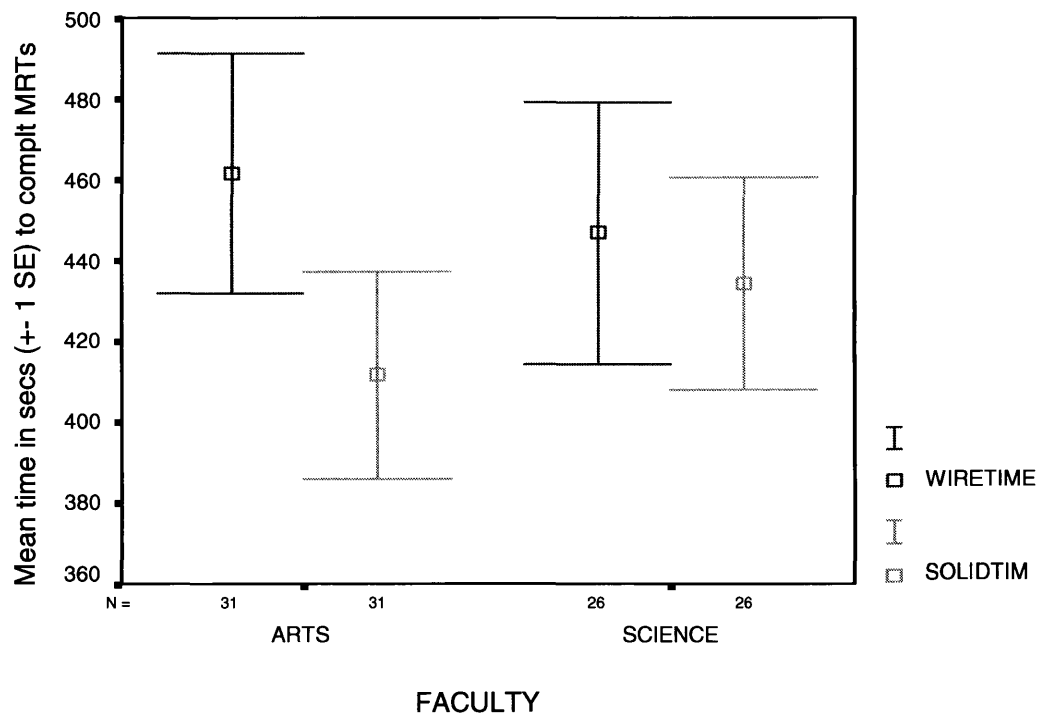


Fig.7.4. Shows the mean time, in seconds (± 1 S.E.) to complete the Wire-frame and Solid MRTs for Faculty, Science, and Arts.

Figures 7.3 and 7.4 show that the wire-frame test was completed more slowly than the solid test for Gender and Faculty, indicating a possible main effect of Task. There were considerable overlaps in performances in figures 7.3 and 7.4, indicating no main effect of Gender or Faculty.

Table 7.3 shows the mean times taken to complete the test and it can be seen that there was little difference in the time taken to complete the two tests with regards to Gender or Faculty. However, the mean time taken to complete the “Wire-frame” test was considerably longer than the “Solid” test. The mean time taken to complete the “Wire-frame” test was (M= 454.75s, S.D. = 164.77) and for the Solid test (M= 421.87s, S.D. = 138.15.)

Time Taken To Complete The “Wire-frame” and “Solid” MRTS (in seconds).

Category		Wire-frame	Solid
Gender	Male	444.45s	422.55s
	S.D.	179.75s	138.49s
	Female	465.43s	421.17s
	S.D.	150.24s	140.34s
Faculty Science		446.63s	434.12s
S.D.		166.28s	133.88s
Arts		461.57s	411.88s
S.D.		165.93s	143.01S

Table 7.3 shows the means and standard deviations for the time taken to complete the Wire-frame and Solid mental rotation tests for Gender and Faculty.

These observable differences for the time taken to complete the “Wire-frame” and “Solid” MRTs was analysed using a Mixed Factor Anova with one within factor:

Task time (Wire-frame and Solid) and three between factors: Gender (Male, Female) and Faculty (Arts, Sciences).

With regards to the within-factor effects, the mixed factor ANOVA revealed a significant main effect of Task ($F(1,49) = 6.03$, $p=0.018$, $p<0.05$ $d=0.22$), whereby the participants were significantly faster at completing the Solid MRT. There were no significant interactions for Time by Gender $F(1,49)= 6.1$, $p=0.44$, Time by Faculty $F(1,49)=1.42$, $p=0.24$, Time by Gender by Faculty $F(1,49)= 0.74$, $p=0.4$.

With regards to between factor effects there were no significant main effects or interactions, Gender $F(1,49)= 0.003$, $p= 0.96$, Faculty $F(1,49)= 0.02$, $p= 0.9$.

7.4 Correlations

There was a strong, positive correlation between the percentage of correct answers in the 2D ROT and the 3D Wire-frame test ($r=0.65$, $p=0.000$, $p<0.001$). These results showed that 42% of the variation in correct answers in the 2D ROT was accounted for by the variation in the number of correct answers in the 3D Wire-frame test.

There was a strong, positive relationship between the percentage of correct answers in the 2D ROT and the 3D Solid test ($r=0.63$, $p=0.000$, $p<0.001$). This result showed that 40% of the variation in correct answers in the 2D ROT was accounted for by the variation in the number of correct answers in the 3D Wire-frame test.

There was a strong, positive relationship between the percentage of correct answers in the 3D Wire-frame and the 3D Solid test ($r=0.63$, $p=0.000$, $p<0.001$). This result showed that 40% of the variation in correct answers in the 2D ROT was accounted for by the variation in the number of correct answers in the 3D Wire-frame test.

The associated probability levels showed that such results were highly unlikely to have arisen by sampling error, assuming the null hypotheses to be true. In other words there was a strong positive relationship between performances on all three tests, if an individual was good at one test, they were good at all three.

7.4.1 Math Ability And Accuracy On the MRTs

		Correlations			
		TWOPERC			
TWOPERC	Pearson Correlation	1			
	Sig. (2-tailed)	.			
	N	57			
WIREPERC	Pearson Correlation	.652**	1		
	Sig. (2-tailed)	.000	.		
	N	57	57		
SOLIDPER	Pearson Correlation	.630**	.646**	1	
	Sig. (2-tailed)	.000	.000	.	
	N	57	57	57	
GRADE	Pearson Correlation	.332*	.345**	.270*	
	Sig. (2-tailed)	.012	.009	.042	
	N	57	57	57	

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 7.4 shows the correlation table for percentage of correct answers on the three MRTs and the math grade of the participants.

Using the information gained from the questionnaire completed by the participants prior to testing, it was possible to look at the relationship between

MRT performance and a participants maths ability as judged by their maths grade at Higher grade or equivalent. From Table 7.4, it can be seen that there was a significant but weak positive relationship between the participants maths grade and their performance on the 2D ROT, the 3D “Wire-frame and 3D “Solid” MRTs ($r=0.33$, $p=0.01$, $p<0.05$; $r=0.35$, $p=0.01$, $p<0.05$ and $r=0.27$, $p=0.04$, $p<0.05$ respectively). This result showed that only 11%, 12% and 7% (respectively) of the percentage of correct answers in the MRTs were accounted for by the variation in the maths grades. Maths ability and spatial ability are shown to be related but in this case, only weakly. However, when taking the male and female scores separately, a different picture emerged as can be seen in Tables 7.5 and 7.6.

Correlations				
MATHS	Pearson Correlation			
	Sig. (2-tailed)			
N				
ROT	Pearson Correlation	.330		
	Sig. (2-tailed)	.087		
	N	28		
WIREFRAM	Pearson Correlation	.264	.548**	
	Sig. (2-tailed)	.175	.002	
	N	28	28	
SOLID	Pearson Correlation	.228	.695**	.582**
	Sig. (2-tailed)	.244	.000	.001
	N	28	28	28

** . Correlation is significant at the 0.01 level (2-tailed).

Table 7.5 shows the correlations between math ability and the percentage of correct answers in the three mental rotation tests for the female participants.

Correlations					
		MATHS			
MATHS	Pearson Correlation	1			
	Sig. (2-tailed)	.			
	N	29			
ROT	Pearson Correlation	.422*	1		
	Sig. (2-tailed)	.022	.		
	N	29	29		
WIREFRAM	Pearson Correlation	.460*	.760**	1	
	Sig. (2-tailed)	.012	.000	.	
	N	29	29	29	
SOLID	Pearson Correlation	.407*	.553**	.706**	1
	Sig. (2-tailed)	.028	.002	.000	.
	N	29	29	29	29

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 7.6 shows the correlations between math ability and the percentage of correct answers in the three mental rotation tests for the MALE participants.

From Table 7.5 it can be seen that with regards to females there was a significant positive relationship between the ROT and Wire-frame test ($r=0.55$, $p=0.002$, $p<0.01$), between the ROT and Solid test ($r=0.69$, $p=0.000$, $p<0.01$) and between the Wire-frame and Solid test ($r=0.58$, $p=0.001$, $p<0.01$), however there was **NO** significant relationship between performance on the MRTs and maths ability.

In contrast, there was a significant positive relationship between the ROT and Wire-frame test ($r=0.76$, $p=0.000$, $p<0.01$), between the ROT and Solid test ($r=0.53$, $p=0.002$, $p<0.01$) and between the Wire-frame and Solid test ($r=0.71$, $p=0.00$, $p<0.01$), and there **WAS** a significant positive correlation between maths ability and performance on the ROT, Wire-frame and Solid tests ($r=0.43$, $p=.002$, $p<0.01$. $r=0.46$, $p=0.01$. $r=0.41$, $p=0.03$, $p<0.05$ respectively).

These results show that maths ability correlates significantly with mental rotation ability for Males but not for Females.

7.5 Discussion

Bodner (1989) suggested that the ROT was solved using Gestalt or analogue processing and Shepard and Metzler style MRTs are solved using analytical processing. The type of processing used cannot be ascertained from this study as performance on all three tests were highly correlated, however the results clearly showed that the way an individual performs on one test will predict their performance on the other two. Showing that the “Wire-frame” and “Solid” 3D tests are valid and reliable tests of mental rotation.

It is possible that Barfield, Sandford, and Foley’s (1988) hybrid theory, of how we are able to mentally represent objects, might explain the results, in that if objects in the test are complex then propositional processing would occur and if the objects are familiar or simple, then analogue processing would be used. The individual simply swaps strategies according to the task at hand. This explanation is supported by Bodner (1989) who also suggested that propositional processes might be used for novel and initially complex problems and analogue for familiar and simple problems.

Of interest to this present research is the fact that there was no significant gender difference found with regards to accuracy in any of the three tests. This, as explained before, goes against the literature. However, the faculty to which a participant belonged did show a significant difference in that on all three tests, those in the Sciences outperformed those in the Arts. This might have been

explained by the understanding that those in the Sciences tend to be more mathematically astute than those in the Arts (Voyer, 1996, Voyer, 1998; Kimura, 1992 and Benbow and Stanley, 1983) and that maths ability and spatial ability would be positively correlated, however, such an explanation cannot be the full story.

Interestingly, in the “wire-frame” and “solid” tests there was a significant interaction between Gender and Faculty but this was found to be between the male Science participants and the male Arts participants. In other words, the males had a greater variance in scores. This suggested that the males with poorer spatial ability scored the low scores (Arts) and those with good spatial ability scored the highest (Science) as was reflected in the correlation between mental rotation and maths ability. With regards to the females, whether they were Arts or Science made no significant difference to their scores, again as reflected in the lack of significant correlation between maths and mental rotation ability. This finding indicated that perhaps they used a spatial strategy other than mental rotation to solve the tests or alternatively they may have used a more language based strategy. It would therefore appear that a maths related strategy was probably not used by the females to solve the MRTs indicating that maths ability and mental rotation ability are independent with regards to females but not for males.

The influence of hormones i.e. testosterone, might also have had a greater impact on the spatial performance of males than it did on females. Those males who were at the lower level or out with the optimum level of testosterone for good

spatial ability showed a marked difference in performance whereas for the females, in this particular sample, there was no significant difference in performance. As there were no significant differences between the male and female performances in the MRTs, or between the females in either faculty, whatever strategies were preferred for solving the tasks they were equally successful.

It should also be noted that the “solid” 3D MRT was the hardest to solve with regards to accuracy. Although there were no significant gender differences as both the males and females found the test harder than the “wire-frame” test, the females did score lower. It might be suggested that the complexity of the task was beginning to differentiate between the abilities of the two sexes but not yet to a significant level. Task complexity could therefore be an area of further research.

Interestingly however, the “Solid” test was completed significantly faster than the “Wire-frame” test, possibly indicating that different strategies were being used. Bodner (1989) suggested that the ROT used Holistic or Analogue processing that required the mental movement of the probe or comparison shape, such as mental rotation and transformation. This approach involves putting together all or some of the alternative parts in order to form a mental image that is then compared to the target or standard shape (Burin and Prieto, (2000)). Bodner also suggested that SM style MRTs requires Analytical or propositional processes whereby the participant identifies key features of the probe or comparison shape and then tries to match them to the target shape. This approach consists of comparing features such as sides, angles and forms of parts of the target shape with features of the

comparison shape (Burin and Prieto, 2000). Deffner (1985) used data from eye fixation recordings to conclude that in a spatial task, Holistic strategies take longer than Analytical strategies; the strategy itself does not guarantee accuracy. In this test however, the SM style “Wire-frame” test, thought to be solved by using Analytical processing took longer to solve than the “Solid” test.

Part Two

7.6 The Virtual Environment.

As the title of the research refers to performance differences within VR it is vital that participants are tested on their spatial awareness, primarily the use of mental rotation in helping individuals to navigate a VE and recall specific information regarding the VE. The importance of mental rotation has already been stated in the first three chapters, not only for solving purely mental rotation tests such as the ROT and Shepard and Metzler style tests but also for successful navigation in the real and virtual world. People are able to keep track of their orientation and their location without any effort even in situations when visual cues disappear momentarily from view. However, occasionally it is necessary to re-orientate ourselves when viewing a familiar environment but from an unfamiliar direction or when our sense of direction or place is mistaken. A simple example would be when emerging from a shop onto a busy street and heading back in the direction you just came from. It is only when you notice that familiar landmarks are not lying in the expected direction that you realise you are going the wrong way. In such a situation it would be advantageous to have the ability to imagine the spatial structure of a given environment from any direction as in a “birds eye” view of

the area, therefore mental rotation and orientation are important to keeping track of movement when navigating a three dimensional environment.

In an experiment by Oman *et al* (2000) they stated that human orientation and spatial cognition partly depends on the way in which we are able to remember sets of visual landmarks and then to imagine their relationship to ourselves but from a different viewpoint. They go on to say that we generally make large body rotations about a single axis, which is aligned with gravity. In other words, we can take it for granted that below our feet is the ground. In the case of astronauts who have to recognise environments rotated in three dimensions, Oman *et al* reported that the astronauts terrestrial ability to imagine the relative orientation of remembered landmarks did not generalise. In their situation, where gravity is absent, and they float into an unfamiliar orientation within their craft, they have a natural tendency to perceive whichever interior surface is below their feet as being the floor. This change in perceived orientation can result in space sickness and causing the astronauts to reach in the wrong direction for remembered objects or to look in the wrong direction for landmarks. Oman *et al*, as part of research carried out for NASA, found that there was a correlation between performance on 3D spatial orientation tasks and 2D/3D mental rotation tasks. Their participants, when imagining their orientation, used a combination of declarative mnemonic rules and mental visualisation techniques to solve orientation tasks.

The second part of phase three required the participants to explore a virtual house whilst wearing shutter glasses, again creating the illusion of three-dimensionality. Having completed the exploration phase they were then tested on their cognitive

map of the VE in that they were read a set of instructions, which required them to recall and find the quickest and most direct routes through the VE to criterion targets. The ability to recall alternative routes to a specific target was tested, as was their ability to recall and draw the layout of the VE. The number of landmarks used by the participants to aid navigation was recorded and finally, the participants were tested on their ability to visualise themselves within the VE and to make directional judgements or name objects relative to their own position within the VE.

The literature, as explained in chapters one, two and three stated that females have poorer spatial abilities than males and this is reflected in their performance within VR. Spatial abilities are necessary for successful navigation of a three dimensional world and tests of mental rotation ability have proved to be the only tests that still consistently produces differences in performance between males and females. The VE tests were designed to look at performances with regards to the exploration of a VE and to ascertain if these results could be correlated with the participants mental rotation performances as measured on the MRTs in phase of testing in this chapter.

The first test was for the participants to navigate according to a set of instructions read to them by the experimenter. The participant had to remember the layout of the house or use landmarks to aid way finding. They had to remember whether to turn right or left at major junctions and visualise where rooms, on different levels at different orientations, were in relation to each other in order to mentally plan

direct routes. The time taken to complete the instructions reflected the participants ability to recall and navigate successfully.

The participants were not allowed to look at the VE in order to answer the remaining tasks. The number of landmarks a participant reported using to aid navigation indicated their preferred strategy for navigation. The number of correctly described routes to a single criterion target would show their ability to recall alternative routes, the inter-connectedness of rooms, doors and passages and to deduce routes that they had possibly not taken during the exploration phase. Success at this task was to determine whether or not the participant used route, landmark or survey knowledge of the VE.

In order to draw an accurate layout of the environment, the participant would have to recall the layout of three floors, one of which was on a different orientation from the other two. Correct placing of the staircases dictated where the rooms lay in respect to the stairs. Mental rotation ability was required to manipulate a three-dimensional mental image of the virtual house.

In the final test the participant had to visualise themselves within the virtual house before they could give appropriate direction judgements or to recall objects relative to their own position. This test would measure visualisation and mental rotation skills. The literature has already stated that females have poorer spatial ability and that this, in turn, would effect their performance in the above-mentioned spatial tasks. The hypotheses therefore were that males would perform better in all of the tasks than the females.

The hypotheses for the VR tests were that:

1. The males would be faster than the females at completing the “way-finding” test.
2. The males would be more accurate at drawing the “layout” of the VE from memory.
3. The males would know more alternative routes to a criterion target than the females.
4. The males would score higher than the females on the “visualisation/direction test.
5. The females would name more landmarks used to aid navigation than the males.

The Method

7.6.1 Design

An experimental approach was used. There were five tests in total, each being of an independent groups design.

1. The IV's for the “Way-finding” test were Gender (male/female) and Faculty (Arts and Social Sciences/Science and Engineering). The DV was the time it took the participants to complete the instructions.
2. The IV's for the Layout test were Gender (male/female) and Faculty (Arts and Social Sciences/Science and Engineering). The DV was the number of stairs and rooms correctly placed in an outline of the virtual house.
3. The IV's for the “alternative routes” test were Gender (male/female) and Faculty (Arts and Social Sciences/Science and Engineering). The DV was the number of correctly recalled routes to a single criterion target.

4. The IV's for the "orientation" test were Gender (male/female) and Faculty (Arts and Social Sciences/Science and Engineering). The DV was the number of correctly recalled items of information.
5. The IV's for the Landmark test were Gender (male/female) and Faculty (Arts and Social Sciences/Science and Engineering). The DV was the number of landmarks used by the participant to aid navigation.

Participants

The same participants were used as for the mental rotation tests. Quota sampling was used to select the 57 participants, 29 males and 28 females, all were right handed and all were either students or academic staff whose discipline fell under one of two faculty headings i.e. Science and Engineering or Arts and Social Sciences. Thirty-one were Arts and 26 were Science. The mean age of the participants was twenty-seven. A payment of £10 was given to the participants who volunteered to take part in the test. All participants had normal or corrected to normal vision. Seven further participants, one male and six females, withdrew from the tests due to nausea caused by sensory conflict whilst exploring the virtual house.

Apparatus

Prior to the tests all of the participants explored a virtual house. The computer game "Swat" was used to provide the house environment. An ELSA Gloria stereo capable video card was installed to convert the 2D-representation into 3D. The participants viewed the computer display screen using Elsa 3D Revelator shutterglasses (see Figure5.6), as used in the 3D MRTs. All participants were

requested to read a participant information sheet and to sign a “participant consent” form. The former explained how the experiment was to be carried out and the latter warned them of the possible nausea that some might experience and conditions that may be exacerbated by the VR experience.

In the case of nausea, participants were advised to halt the test immediately. (See Appendices 4 and 5 for copies of the information and consent sheets). There were 4 paper and pencil tests that required the participants to recall information from memory. (Appendices 6 to 10 show the instructions and answer sheets for the four paper and pencil tests can be seen along with a set of the navigational instructions read out to the participants by the experimenter for the “way-finding” test) a stopwatch was used to time the participants carrying out the navigational instructions.

Procedure

Each participant was brought into the experimental room and tested individually. An information sheet and consent form were given to each participant to read and sign. The sheet informed them of the possibility of feeling nauseous as they explored the house. If they decided not to continue with the test because of such nausea then they were free to do so at any point. The sheet also informed them of conditions that may be exacerbated by the VR experience. After signing the consent form they were asked to wear the Elsa shutterglasses and to view a virtual house presented on computer screen (see figure 7.7). If participants needed to wear their own glasses, the shutterglasses could be worn over the top of prescription glasses.

The experimental room was in darkness to avoid flicker caused by the interaction between the overhead fluorescent lights and the transmission of signals from the transmitter on the computer screen to the Elsa shutterglasses. The participants were each asked if the environment they were looking at conveyed the impression of depth. Each participant first viewed the entrance hall view of the sitting area as can be seen in figure 7.5 and were asked to describe what they could see. All of the participants confirmed that the small table looked as if it was closer to them than the dining table in the background, and that they had the impression that they could look down the corridor on the right if they looked around the corner wall. All confirmed that they “felt” they were experiencing three dimensionality.

If it was necessary, the participants were shown how to use the direction arrows on the keyboard and the mouse to move about the house. They were shown that in order to open the doors in the house they were to press the space bar. A triangle in the centre of the screen was used as a self-position marker. The participant was then left alone to explore the house having been informed that there were three floors, a garden and a swimming pool. They were also advised to leave all the doors open. Each participant was given 15 minutes to explore at his or her leisure.



Figure 7.5 shows the entrance hall and living room in the virtual house. The doors could be opened and closed by pressing the space bar

Test 1. Way-finding test.

When the experimenter returned, the participant was asked if they were feeling well and were prepared to continue with the test. If the participant felt they were unable to continue then they were free to discontinue. As mentioned earlier, seven participants withdrew at this stage due to feeling nauseas; six were female and one male. If the participant was happy to continue, the experimenter asked the participant to position their virtual self at the sofa in the sitting room of the virtual house as indicated by the triangle on the screen. It was then explained that by pressing the right button on the mouse a “shot” would be fired. As the virtual environment was adapted from a “shoot ‘em up game” it was possible to shoot targets and leave a bullet hole. The procedure, named “tagging” was used to

indicate that the participants had visited the criterion targets as directed and had not taken shortcuts.

The experimenter then read out the first of the five instructions (see appendix 6) to the participant. The participant confirmed that they understood the instructions and were then timed, in minutes and seconds, as they carried out the instructions. If the participant did not understand, then the experimenter clarified the instructions and terminology until the participant was clear with what he or she had to do. There were occasions where the terminology had to be clarified, such as the terms “den”, study room, utility room and granny flat. The participant completed each set of instructions before being read the next set. All five instructions, which were counterbalanced, were completed with the participant receiving no help once the timer had begun. Once completed, the participant was asked to remove the glasses and the room was again illuminated.

At this stage, the participants had not only received 15 minutes exploration time but they had also traversed the VE using a range of routes. Although they had not been instructed to learn or commit to memory the layout of the environment, they would have constructed a schema or mental map of the layout. The four paper and pencil tests were then administered.

Test2. Layout

For test two, participants were presented with the outlines of the three floors on an A4 sheet of paper (see appendix 7). They were advised that the “granny flat” was not to scale, as it would have been too small for them to draw in the required details. They were then asked to draw in the locations of the rooms and staircases

as accurately as possible. If there was a room within a room e.g. a bathroom within a bedroom then they were to make that distinction, naming the rooms where possible. Scores were calculated by giving a point to each room correctly named and located and stairs drawn in the correct position. The participants were not told that the granny flat lay on a different orientation from the ground and first floors. This made a difference when drawing in the stairs and the subsequent layout of the rooms.

Test 3. Alternative Routes Test

For test three, participants were asked to visualise themselves in the office in the virtual house. They were then to imagine that a stranger to the house was asking them for directions to the swimming pool. It was explained to the participant that there were three routes from the office to the swimming pool. One route was the most direct and most obvious, the second was a longer route and the third was not so obvious and required negotiating doorways. As a precaution, the participants were advised that none of the routes required the stranger to go upstairs and come back down again i.e. there were no “trick” routes. The participants wrote their instructions as clearly as possible for as many of the three routes as they could recall, they received one point for every correctly recalled route (see appendix 8).

Test 4. Orientation Test.

The participant was given five orientation questions to answer (see appendix 9).

The questions required the participant to visualise themselves in certain areas of the virtual house. They were then either to state a particular direction in which they should travel in order to answer the question or to name a particular object that was located either to the side or behind them. For instance, question one

required the participants to imagine themselves in the “playroom” of the virtual house, in front of and looking at the pin-board. They then had to name what would have been immediately behind them. The correct answer would have been large building blocks. Participants received one point for every question answered correctly.

Test 5. Landmarks.

For the final test, participants were asked to name the landmarks they used for navigating around the house (see appendix 10). A landmark was explained, as being any object that the participant might have used to help them find their way around the house and garden, for example, in the main hall there was a prominent flower table complete with pot plant. The table could be seen from the far end of the lounge, the kitchen and the den and marked where the hallway to the stairs was to be found.

If the participant did not feel they used landmarks *per se*, then they were asked to write in their own words how they found their way about the house, especially when carrying out the way finding instructions. Every landmark scored one point. If the participant wrote that they had a mental map and did not use landmarks (or something similar) then they received one point.

Results of the VE Tests.

7.6.2 Test 1. WAY-FINDING.

The data was analysed and the means and standard deviations for the time taken to complete the way-finding test is presented in Table. 7.7. From the results, it can

be seen that the Males were marginally faster than the Females and the Science participants were faster than the Arts.

WAY-FINDING TEST			
		Mean	S.D.
Gender	Male	7.05m	2.28m
	Female	7.19m	1.86m
Faculty	Arts	7.28m	1.91m
	Science	6.92m	2.26m

Table 7.7 Means and standard deviations for the time taken to complete the way-finding instructions according to the Gender and Faculty.

To test the data further, the time taken to complete the navigation instructions was analysed using analysis of variance with two between participant factors of Gender (male vs females) and Faculty (Arts and Social Sciences vs Science and Engineers) which showed that there was a significant main effect of Faculty ($F(1,49) = 4.52, p = 0.04, p < 0.05$) but not for Gender ($F(1,49) = 0.09, p = 0.76, p > 0.05$). The Science participants were significantly faster than the Arts.

Test Two. LAYOUT.

The data was analysed and the means and standard deviations for the mean number of correctly placed rooms etc is presented in Table. 7.8. Results showed that the Males were more accurate than the Females, the Sciences more accurate than the Arts.

	GENDER		LAYOUT TEST FACULTY	
	Males	Females	Arts	Science
Layout recall	18.86	14.50	14.48	19.38
Standard Deviation	5.64	6.79	6.66	5.42

Table 7.8 shows the mean number of correctly placed rooms etc. in the LAYOUT test with the two factors Gender and Faculty.

To test the data further, analysis of variance was used, with two between-participant factors of Gender (male vs females) and Faculty (Arts and Social Sciences vs Science and Engineers). This showed that there was a highly significant main effect of Faculty ($F(1,49) = 9.24, p=0.004, p<0.01, d=0.81$). The Science participants scored significantly higher than the Arts participants. There were no significant main effects for Gender $F(1,49) = 1.64, p=0.2$.

There was no significant interactions for Gender by Faculty $F(1,49) = 1.99, p=0.17$,

TEST Three. Alternative Routes

The data was analysed and the means and standard deviations for the number of correctly recalled routes is presented in Table. 7.9. From the results it can be seen that the males recalled more than the Females and the Sciences more than the Arts.

ALTERNATIVE ROUTES

Factor	Level	Mean	S.D.
Gender	Male	2.24	0.91
	Female	1.89	0.11
Faculty	Arts	1.84	1.10
	Science	2.35	0.78

Table 7.9. Means and standard deviations for the ROUTE TEST with three factors, Gender and Faculty.

To test the data further, the number of accurately recalled routes to the target criterion was analysed using analysis of variance which showed that there were no significant main effects of Gender or Faculty: Gender $F(1,49) = 1.66$, $p = 0.69$, and Faculty $F(1,49) = 2.81$, $p = 0.1$.

There were no significant interactions for Gender by Faculty $F(1,49) = 0.36$, $p = 0.55$

Test Four. Orientation

The data was analysed and the means and standard deviations for the number of correct answers is presented in Table. 7.10. From the results it can be seen that the males were more accurate than the Females, The Sciences more accurate than the Arts.

ORIENTATION TEST

Factor	Level	Mean	S.D.
Gender	Male	3.24	0.95
	Female	3.07	0.81
Faculty	Arts	1.84	1.10
	Science	2.35	0.78

Table 7.10 Means and standard deviations for the ORIENTATION test with three factors, Gender and Faculty.

To test the data further, the number of correct answers given in the Orientation test was analysed using an analysis of variance which showed that there was a highly significant main effect of Faculty ($F(1,49)=2.56, p=0.04, p<0.05, d=0.54$) with the Science participants outperforming the Arts. There were no significant effects of Gender ($F(1,49)=1.55, p=0.22, p>0.05$).

There were significant interactions for Gender by Faculty ($F(1,49)=9.31, p=0.004, p<0.01$) as can be seen in figure 7.6.

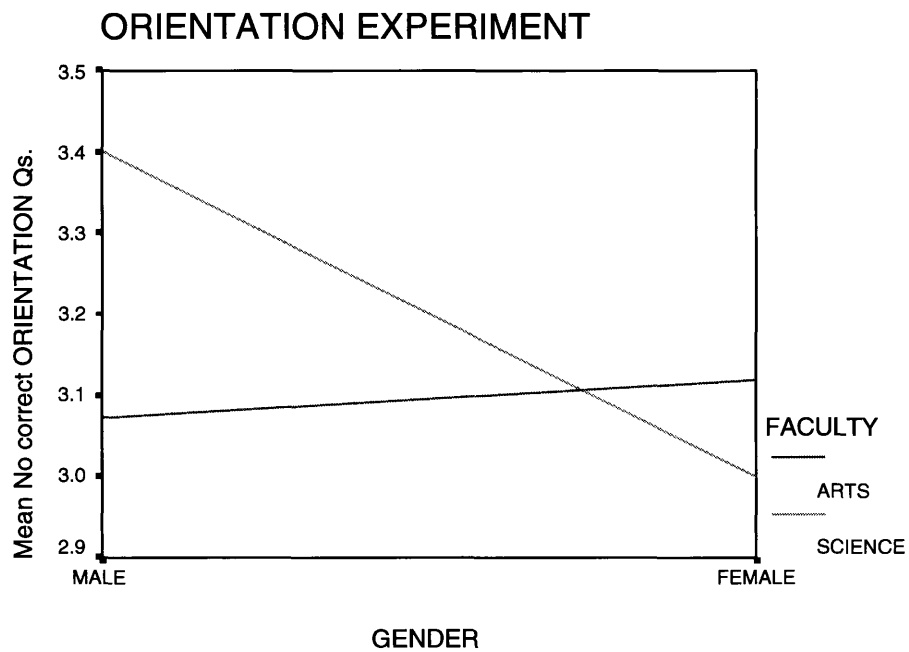


Fig 7.6 shows the interaction between Gender and Faculty in the Orientation Test.

Independent t-tests, with adjustment for the number of comparisons, showed that there were no significant differences in performance between the males in the Arts and Science faculties ($t(27) = 0.36, p > 0.05$) or between the females in the Arts and Sciences ($t(26) = 0.7, p > 0.05$).

Test Five. Landmark

The data was analysed and the means and standard deviations for the number of landmarks is presented in Table. 7.11. From the results it can be seen that the Females used more landmarks than the Males and the Sciences used more than the Arts.

LANDMARK TEST

Condition	level	Mean	S.D.
Gender	Male	2.83	2.59
	Female	4.25	3.99
Faculty	Arts	3.32	3.51
	Science	3.77	3.35

Table 7.11. Means and standard deviations for the number of landmarks for the three factors Gender and Faculty.

To test the data further, the number of landmarks used was analysed using an analysis of variance with two between subject factors of Gender and Faculty, which showed that there were no significant main effects of Faculty ($F(1,49) = 1.97, p = 0.17, p > 0.05$) or Gender ($F(1,49) = 0.72, p = 0.4, p > 0.05$).

There were no significant interactions for Gender by Faculty ($F(1,49) = 0.27, p = 0.6, p > 0.05$).

7.7 Correlations in Mental Rotation and navigation tests.

A correlation matrix was constructed from variables taken from the MRTs, VE tests and information taken from the questionnaire i.e. maths ability, computer experience and video game experience. The variables used were:

1. The percentage of correct answers given in the three MRTs,
2. The time taken to complete the Wire-frame and Solid tests,
3. The number of Landmarks used in the navigation test,
4. The number of correctly recalled rooms etc, in the Layout test,
5. The number of accurately recalled routes in the Alternative Route tests,
6. The number of correctly answered questions in the Orientation test,
7. The time taken to complete the way-finding instructions,
8. The maths grades of the participants,
9. The number of hours spent playing computer games by the participants,
10. The number of years computer experience had by the participant.

The full correlation matrix has been presented in Table 7.12, however, for ease of comprehension and discussion, the relevant significant correlations are presented in smaller, individual tables.

Correlations

		TWO PERC												
TWO PERC	Pearson Correlation	1												
	Sig. (2-tailed)	.												
	N	57												
WIRE PERC	Pearson Correlation	.852**	1											
	Sig. (2-tailed)	.000	.											
	N	57	57											
WIRE TIME	Pearson Correlation	-.252	.033	1										
	Sig. (2-tailed)	.058	.807	.										
	N	57	57	57										
SOLID PERC	Pearson Correlation	.830**	.846**	-.026	1									
	Sig. (2-tailed)	.000	.000	.846	.									
	N	57	57	57	57									
SOLID TIM	Pearson Correlation	-.256	.016	.790**	-.013	1								
	Sig. (2-tailed)	.055	.908	.000	.928	.								
	N	57	57	57	57	57								
LANDMARK	Pearson Correlation	.098	-.058	-.085	.168	-.051	1							
	Sig. (2-tailed)	.467	.868	.532	.211	.706	.							
	N	57	57	57	57	57	57							
LAYOUT	Pearson Correlation	.572**	.513**	-.176	.438**	-.133	-.057	1						
	Sig. (2-tailed)	.000	.000	.190	.001	.322	.671	.						
	N	57	57	57	57	57	57	57						
ROUTE	Pearson Correlation	.380**	.324*	-.416**	.186	-.141	-.169	.517**	1					
	Sig. (2-tailed)	.004	.014	.001	.166	.297	.208	.000	.					
	N	57	57	57	57	57	57	57	57					
ORIENT	Pearson Correlation	.163	.243	-.173	.070	-.205	-.072	.368**	.361**	1				
	Sig. (2-tailed)	.225	.069	.199	.806	.127	.597	.005	.006	.				
	N	57	57	57	57	57	57	57	57	57				
NAV TIME	Pearson Correlation	-.055	-.041	.092	-.057	.095	.070	-.093	-.101	-.087	1			
	Sig. (2-tailed)	.686	.761	.495	.676	.484	.603	.491	.465	.518	.			
	N	57	57	57	57	57	57	57	57	57	57			
GRADE	Pearson Correlation	.332*	.346**	-.036	.270*	-.079	-.075	-.012	-.007	-.058	-.104	1		
	Sig. (2-tailed)	.012	.009	.792	.042	.558	.577	.931	.958	.670	.440	.		
	N	57	57	57	57	57	57	57	57	57	57	57		
PLAY	Pearson Correlation	.224	.135	-.365**	.145	-.300*	.090	.261*	.110	.114	-.005	-.237	1	
	Sig. (2-tailed)	.094	.317	.005	.282	.023	.507	.050	.413	.399	.971	.076	.	
	N	57	57	57	57	57	57	57	57	57	57	57	57	57
EXPERIEN	Pearson Correlation	.191	.138	-.403**	.053	-.220	-.092	.132	.314*	.024	.088	.029	.246	
	Sig. (2-tailed)	.155	.305	.002	.898	.099	.497	.326	.017	.862	.513	.830	.065	
	N	57	57	57	57	57	57	57	57	57	57	57	57	57

Table 7.12 shows the correlations between the variables in the MRTs, Navigation tests, Math ability, computer experience, the number of hours spent playing computer games and the number of years computer experience.

Correlations

		SOLIDTIM		
SOLIDTIM	Pearson Correlation	1		
	Sig. (2-tailed)	.		
	N	57		
WIRETIME	Pearson Correlation	.790**	1	
	Sig. (2-tailed)	.000	.	
	N	57	57	
PLAY	Pearson Correlation	-.300*	-.365**	1
	Sig. (2-tailed)	.023	.005	.
	N	57	57	57

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 7.13 shows the correlation between the time taken to complete the Solid and Wire-frame MRTs and the number of hours spent playing computer games per week.

Table 7.13 shows that there was a strong, positive relationship between the time taken to complete the Solid 3D MRT and the Wire-frame 3D MRT ($r=0.79$, $p=0.000$, $p<0.001$). This result showed that 62% of the variation in time taken in the Solid MRT was accounted for by the variation in the time taken in the 3D Wire-frame MRT.

There was a weak, negative relationship between the time taken to complete the Wire-frame 3D MRT and the Solid 3D MRT with the number of hours spent playing computer games, i.e. the more hours playing the less time taken to complete the MRT ($r= -0.37$, $p=0.005$, $p<0.001$ and $r= -0.3$, $p=0.02$, $p<0.001$ respectively). This result shows that only 14% and 9% of the variation in time taken in the Wire-frame MRT was accounted for by the variation in the number of hours spent playing computer games. The associated probability levels showed that the results were highly unlikely to have arisen by sampling error, assuming the null hypothesis to be true. These results showed that the amount of experience

and practice an individual has at playing computer games may have had an effect on the speed at which they can carry out mental rotation tests.

7.7.2. The percentage of correct answers in 2D ROT, 3D Wire-frame and 3D Solid test and the number of hours spent playing computer games per week

		Correlations			
		PLAY			
PLAY	Pearson Correlation	1			
	Sig. (2-tailed)	.			
	N	57			
WIREPERC	Pearson Correlation	.135	1		
	Sig. (2-tailed)	.317	.		
	N	57	57		
TWOOPERC	Pearson Correlation	.224	.652**	1	.630**
	Sig. (2-tailed)	.094	.000	.	.000
	N	57	57	57	57
SOLIDPER	Pearson Correlation	.145	.648**	.630**	1
	Sig. (2-tailed)	.282	.000	.000	.
	N	57	57	57	57

** . Correlation is significant at the 0.01 level (2-tailed).

Table 7.14 shows the correlation between the percentage of correct answers in the three MRTs and the amount of hours spent playing computer games.

Table 7.14 shows that there were NO significant relationships between the amount of hours played and the accuracy of the participant on the three MRTs. The fact that there was a significant relationship between the accuracy scores in the three MRTs has already been reported.

7.7.3 Number of years computer experience and accuracy on the three MRTs.

Correlations

		TWOPERC			
TWOPERC	Pearson Correlation	1			
	Sig. (2-tailed)	.			
	N	57			
WIREPERC	Pearson Correlation	.652**	1		
	Sig. (2-tailed)	.000	.		
	N	57	57		
SOLIDPER	Pearson Correlation	.630**	.646**	1	
	Sig. (2-tailed)	.000	.000	.	
	N	57	57	57	
EXPERIEN	Pearson Correlation	.191	.138	.053	
	Sig. (2-tailed)	.155	.305	.696	
	N	57	57	57	

** . Correlation is significant at the 0.01 level (2-tailed).

Table 7.15 shows the correlation between the percentage of correct answers in the three MRTs and the number of years computer experience had by the participants.

From Table 7.15 it can be seen that there was no significant relationship between computer experience and the percentage of correct answers in the three MRTs

7.7.4 Performance on the MRTs and VE tests:

Correlations

		TWOPERC					
TWOPERC	Pearson Correlation	1					
	Sig. (2-tailed)	.					
	N	57					
WIREPERC	Pearson Correlation	.652**	1				
	Sig. (2-tailed)	.000	.				
	N	57	57				
SOLIDPER	Pearson Correlation	.630**	.646**	1			
	Sig. (2-tailed)	.000	.000	.			
	N	57	57	57			
LANDMARK	Pearson Correlation	.098	-.058	.168	1		
	Sig. (2-tailed)	.467	.668	.211	.		
	N	57	57	57	57		
LAYOUT	Pearson Correlation	.572**	.513**	.438**	-.057	1	
	Sig. (2-tailed)	.000	.000	.001	.671	.	
	N	57	57	57	57	57	
ROUTE	Pearson Correlation	.380**	.324*	.186	-.169	.517**	1
	Sig. (2-tailed)	.004	.014	.166	.208	.000	.
	N	57	57	57	57	57	57
ORIENT	Pearson Correlation	.163	.243	.070	-.072	.368**	.361**
	Sig. (2-tailed)	.225	.069	.606	.597	.005	.006
	N	57	57	57	57	57	57

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 7.16 shows the correlation between the percentage of correct answers in the three MRTs and performance in the VE Test (landmark, layout, route and orientation)

Table 7.16 shows that there was a significant positive relationship between the participants performance on the 2D ROT and their performance in the Layout and Alternative Route tests ($r=0.57$, $p=0.00$, $p<0.01$ and $r=0.38$, $p=0.00$, $p<0.01$ respectively.) This result shows that only 32% and 16% of the variation in the Layout test and Route Knowledge test can be accounted for by the variation in the percentage of correct answers given in the ROT.

There was a significant positive relationship between the participants performance on the 3D wire-frame test and their performance in the Layout and Route Knowledge test ($r=0.51$, $p=0.00$, $p<0.01$ and $r=0.32$, $p=0.01$, $p<0.05$). This result shows that only 26% and 10% of the variation in the Layout test and Route Knowledge test can be accounted for by the variation in the percentage of correct answers given in the Wire-frame test.

There was also a significant positive correlation between the participants performance on the 3D solid test and their performance in the Layout ($r=0.44$, $p=0.001$, $p<0.01$). This result shows that only 19% of the variation in the Layout test can be accounted for by the variation in the percentage of correct answers given in the Solid test.

7.7.5. VE tests, math grade, computer experience and hours spent playing computer games per week.

Correlations

		LANDMARK						
LANDMARK	Pearson Correlation	1						
	Sig. (2-tailed)	.						
	N	57						
LAYOUT	Pearson Correlation	-.057	1					
	Sig. (2-tailed)	.671	.					
	N	57	57					
ROUTE	Pearson Correlation	-.169	.517**	1				
	Sig. (2-tailed)	.208	.000	.				
	N	57	57	57				
ORIENT	Pearson Correlation	-.072	.368**	.361**	1			
	Sig. (2-tailed)	.597	.005	.006	.			
	N	57	57	57	57			
GRADE	Pearson Correlation	-.075	-.012	-.007	-.058	1		
	Sig. (2-tailed)	.577	.931	.958	.670	.		
	N	57	57	57	57	57		
PLAY	Pearson Correlation	.090	.261*	.110	.114	-.237	1	
	Sig. (2-tailed)	.507	.050	.413	.399	.076	.	
	N	57	57	57	57	57	57	
EXPERIEN	Pearson Correlation	-.092	.132	.314*	.024	.029	.246	1
	Sig. (2-tailed)	.497	.326	.017	.862	.830	.065	.
	N	57	57	57	57	57	57	57

** . Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 7.17 shows the correlations between performances on the VE tests with math ability, computer experience and number of hours playing computer games.

Table 7.17 shows that mathematics ability did not have a significant correlation with any of the VE tests.

Other significant correlations not already mentioned were between the number of hours spent playing computer games and the Layout test ($r=0.26$, $p=0.05$, $p<0.05$) and between the number of years computer experience and Route Knowledge ($r=0.31$, $p=0.02$, $p<0.05$)

There was a weak, positive relationship between the Route knowledge test and the Layout test ($r= .52$, $p= 0.000$, $p<0.001$). This result showed that only 27 % of the variation in the number of correctly recalled routes in the Route knowledge test was accounted for by the variation in the number of correctly recalled rooms etc. in the Layout test.

There was a weak, positive relationship between the number of correctly answered Orientation questions and the number of correctly recalled rooms etc. in the Layout test ($r=0.37$, $p= 0.005$, $p<0.05$). This result shows that only 14% of the variation in the number of correctly answered Orientation questions was accounted for by the variation in the number the number of correctly recalled rooms etc. in the Layout test.

There was a weak, positive relationship between the number of correctly answered Orientation questions and the number of correctly routes in the Route Knowledge test ($r=0.36$, $p= 0.006$, $p<0.05$). This result shows that only 13% of the variation in the number of correctly answered Orientation questions was

accounted for by the variation in the number of correctly recalled routes in the Routes Knowledge test.

The associated probability level showed that such a result was highly unlikely to have arisen by sampling error, assuming the null hypothesis to be true.

7.7.6. Correlation between the Three MRTs and the Layout, Route and Orientation tests for Males and Females separately.

Correlations^a

		TWOPERC					
TWOPERC	Pearson Correlation	1					
	Sig. (2-tailed)	.					
	N	29					
WIREPERC	Pearson Correlation	.760**	1				
	Sig. (2-tailed)	.000	.				
	N	29	29				
SOLIDPER	Pearson Correlation	.553**	.706**	1			
	Sig. (2-tailed)	.002	.000	.			
	N	29	29	29			
LAYOUT	Pearson Correlation	.601**	.583**	.519**	1		
	Sig. (2-tailed)	.001	.001	.004	.		
	N	29	29	29	29		
ROUTE	Pearson Correlation	.444*	.361	.294	.395*	1	
	Sig. (2-tailed)	.016	.054	.121	.034	.	
	N	29	29	29	29	29	
ORIENT	Pearson Correlation	.181	.282	.167	.426*	.342	1
	Sig. (2-tailed)	.348	.139	.387	.021	.069	.
	N	29	29	29	29	29	29

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

a. gender= MALE

Table 7.18 shows the correlation between the MALE performances on the MRTs and the Layout, Route and Orientation tests

Table 7.18 shows that for the Males there were significant, positive relationships between the 2D, Wire-frame and Solid MRTs and the Layout test ($r=0.6$, $p=0.001$, p , 0.01. $r=0.58$, $p=0.001$, $p<0.01$. $r=0.52$, $p=0.004$, $p<0.01$ respectively). The 2D test and performance on the Alternative Route test had a significant positive relationship ($r=0.44$, $p=0.02$, $p<0.05$). There was also a significant positive

relationship between performances on the Layout and Alternative Route test ($r=0.43$, $p=0.02$, $p<0.05$)

This result shows that only 13% of the variation in the number of correctly answered Orientation questions was accounted for by the variation in the number of correctly recalled routes in the Routes Knowledge test.

Correlations^a

		TWOPERC					
TWOPERC	Pearson Correlation	1					
	Sig. (2-tailed)	.					
	N	28					
WIREPERC	Pearson Correlation	.549**	1				
	Sig. (2-tailed)	.002	.				
	N	28	28				
SOLIDPER	Pearson Correlation	.695**	.582**	1			
	Sig. (2-tailed)	.000	.001	.			
	N	28	28	28			
LAYOUT	Pearson Correlation	.539**	.479**	.312	1		
	Sig. (2-tailed)	.003	.010	.106	.		
	N	28	28	28	28		
ROUTE	Pearson Correlation	.303	.284	.034	.566**	1	
	Sig. (2-tailed)	.117	.143	.864	.002	.	
	N	28	28	28	28	28	
ORIENT	Pearson Correlation	.123	.185	-.102	.299	.372	1
	Sig. (2-tailed)	.533	.346	.606	.122	.051	.
	N	28	28	28	28	28	28

** . Correlation is significant at the 0.01 level (2-tailed).

a. gender = FEMALE

Table 7.19 shows the correlation between the FEMALE performances on the MRTs and the Layout, Route and Orientation tests

Table 7.19 shows that for the Females there were significant, positive relationships between the 2D and Wire-frame MRTs and the Layout test ($r=0.54$, $p=0.003$, p , 0.01. $r=0.48$, $p=0.01$, $p<0.05$.respectively). There was also a significant positive relationship between performances on the Layout and Alternative Route test ($r=0.57$, $p=0.02$, $p<0.05$).

This result shows that only 13% of the variation in the number of correctly answered Orientation questions was accounted for by the variation in the number of correctly recalled routes in the Routes Knowledge test

7.8 Discussion.

The results of the tests following the exploration of the virtual house were surprising in that the hypotheses were not supported. There were no significant differences in the performances between the males and females. In the Layout test, the participants recalled a mental picture of the virtual house in order to locate where the rooms were on each of the three floors. The accurate positioning of the staircases was important, for if the participant placed them incorrectly; they then recalled the rooms on the floor the stairs opened onto, in reverse order. The basement or granny flat also lay on a different orientation from the other two floors, which made the recall of the connection between the floors more complex. A surveyors or birds eye view of the floors would have given the best “picture”.

The same with the Alternative Route test where the participants were asked to visualise and then write an account of how they would travel from the library to the swimming pool. There were three routes that the participant might have taken during their exploration of the house, one that was obvious and direct and one that was a less direct route but still relatively easy to work out. The third route involved thinking about the various doorways and inter-connecting rooms and deducing the correct route if it had not actually been traversed during the exploration time. Once again, a surveyors knowledge of the house would have allowed the participant the best opportunity to visualise the layout and

“interconnectedness” of the rooms as route knowledge *per se* would not have helped the participant work out a route they had possibly not taken.

The Orientation test was perhaps the most surprising result that once again produced no significant difference in performance. Participants were required to visualise themselves at certain locations within the virtual house. They were then asked to recall what would be behind them or to the right of them or to give directions. This involved mentally re-orientating themselves within the VE and keeping track of the environment relative to themselves.

The Landmark test stood out in that the participants were asked to recall the number of landmarks they used to navigate around the house and gardens. The assumption was that females would use more landmarks than males (Dabbs, Chang, Strong and Milun 1999, Sandstrom, Kauffman and Heuttel, 1998, Eals and Silverman, 1994), however, there was again no gender difference. This could be explained, as there was some confusion as to what was a landmark. Many participants listed objects that were more descriptors for identifying each room, which in turn, might have been used as a navigational aid, rather than identifying specific objects that aided way finding. As Venison (1999) suggested, landmarks used between junctions are more likely to be markers, confirming that the navigator is travelling in the correct direction.

With regards to the time it took participants to complete the way finding instructions; the Arts participants were slower than the Science participants. As the Sciences scored significantly higher than the Arts in the Layout and

Orientation Tests, the mental picture that the Science participants held of the environment may have been more complete or accurate. Such an accurate mental map would have aided changes in directions and the following of routes, therefore preventing them from taking wrong turnings and adding time to their completion rate.

It has to be said that there was no significant negative correlations between the amount of hours spent playing computer games or the number of years computer experience with the time taken to complete the instructions.

7.8.1 Correlations

The number of hours spent playing computer games had a significant negative correlation with the time taken to complete the two computer generated 3D mental rotation tests, indicating that experience or practice playing computer games, which are invariably spatial by nature, may indeed increase spatial skills. This supports the findings of Subrahmanyam, Greenfield, Kraut and Gross, E. (2001) who stated that with regards to computer games, spatial representation involves the spatial visualisation of objects, or the ability to deal with 2-D images seen on a computer screen and interpret them in a hypothetical 3-D space. Spatial skills help players "read" the information on the screen, and repeated practice enhances spatial skills. Unfortunately, the number of hours spent playing computers games may have made them faster but it did not necessarily make them any more accurate on the MRTs, neither did the number of years computer experience.

There was, however, a significant positive correlation between the numbers of hours spent playing computer games and the accurate layout of the house and gardens. In order to be successful at many computer games, the player must remember the layout of the environment in order to escape, hide, ambush, backtrack and indeed navigate around the gaming scenario. The correlation between the number of years computer experience had by a participant and their scores on the route test is also not surprising. Making sense of a computer interface and navigating the Internet, all require spatial skills and the ability to remember the spatial layout of interconnected sites and pages. The organisation of spatial representations is necessary for the successful navigation of both hyperspace and virtual environments.

As stated previously, there were significant positive correlations between the accuracy scores in the three MRTs and these in turn had significant positive correlations with the Alternative Route and Layout tests. These results indicated that there was a relationship between mental rotation ability and the tasks that involved the accurate visualisation of the environment particularly from a survey knowledge perspective, Survey knowledge is spatially structured, like a map, and is characterised by the ability to take an exocentric viewpoint (Lynch, 1960). Males however, it has been suggested, develop survey knowledge whereas females develop landmark or route knowledge. In the case of the virtual house and garden, the environment was small scaled and familiar therefore the females were able to form a surveyors knowledge of the scene.

Mental rotation ability did not correlate with the orientation test that required participants to visualise themselves at different positions within the house and to give directions or to recall objects in relation to the participants virtual self within the environment.

However, when male and female performances were taken separately, tables 7.18 and 7.19 show that for males, performance on all three MRTs correlated significantly with performance on the Layout test and only the 2D ROT with the Alternative Route test. With regards the females, performance on the ROT and the 3D “Wire-frame” test correlated with the Layout test and none correlated with the Alternative Route test. These correlational findings suggest that further research is required to identify the types of strategies that are used to solve the various types of tasks people are asked to solve when navigating a virtual environment. It is important to know if using, for example, mental rotation, solves a particular task in order to ascertain whether or not training in mental rotation skills is necessary or practical.

It is pointless training one particular spatial skill if another is actually required especially as it is not guaranteed that one will generalise to the other. It is also necessary to ascertain whether or not males and females use different strategies to solve the same problems as the present findings suggest that this is indeed the case and that mental rotation ability and indeed math ability may have to be considered differently with regards to males and females.

However, the Layout test correlated significantly with mental rotation ability for the males and females, all-be-it that the female correlation was weaker than the males. That mental rotation might have been used to accurately draw the Layout of the VE is justifiable in that, as stated previously, the participants had to not only visualise the layout of each of the three floors, they had to picture the floors on top of each other in order to locate the position of the stairs on one floor and where they emerged on the floor above. When asked how they recalled the layout of the floors, many participants stated that they started with the location of the stairs, particularly for the upper floor. If the stair were positioned emerging at the wrong corner of the floor outline, then the layout would be incorrect with respect to the layout of the floor below. The same for the stairs going down into the granny flat, although theoretically the easiest floor to remember, the incorrect positioning of the stairs, relative to the ground and first floors, would mean that the rooms were drawn in the reverse order. A further complication was that the granny flat lay on a North South bearing whereas the upper floors both ran on a West East bearing. One efficient way of drawing the layout of the VE was to imagine the skeletal house in 3D, as in a 3D architects drawing, with all the staircases and floors in place. By mentally rotating the image it would be possible to “see” the content of each floor.

To complicate matters further however, attention must be drawn to the finding that math ability and mental rotation ability had a significant positive correlation for males but not for females, math ability did not have a significant positive correlation with any of the VE tests for both the males and females and yet mental rotation ability had a significant positive correlation with performance on the

Layout test for both males and females. This is indeed a conundrum but can possibly be explained by suggesting that another variable, namely Spatial Visualisation Ability, could be a factor that solves the problem.

Taking males first:

Maths Ability significantly correlated with Mental Rotation Ability but not with performance on the Layout test but Mental Rotation Ability did significantly correlate with performance on the Layout Test. The Layout test had significant correlations with both the Alternative Route and Orientation tests.

For Females:

Math ability had no significant correlation with the MRTs or the VE tests. Mental rotation ability had a significant correlation with the Layout test, which in turn had a significant correlation with the Route test. The Orientation test had no significant correlation.

Spatial Visualisation Ability could theoretically bind the variables together. Voyer, Voyer and Bryden, 1995 conducted a large-scale meta-analysis into spatial abilities and stated that there are three types of spatial ability: spatial perception, mental rotation and spatial visualisation. Spatial perception was defined as being the ability to ignore distracting information and identifying spatial relations. It also involves the ability to perceive the location of something vertically and or horizontally. Mental rotation is the ability to rotate two and three-dimensional objects, quickly and accurately, in the imagination. Finally, spatial visualisation is the ability to produce the correct solution when given complex spatial information, that requires taking several steps to solve.

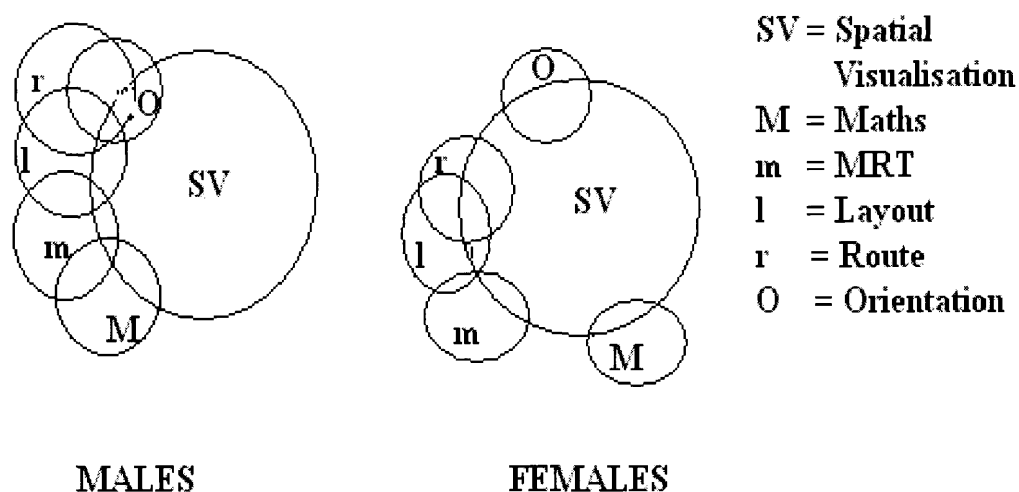


Fig 7.7 shows the possible influence of Spatial Visualisation on Math Ability, Mental Rotation Ability and performances on the VE tests plus their interactions with each other

Figure 7.7 illustrates how Maths Ability and Mental Rotation Ability overlap for Males but not for Females but Spatial Visualisation is important for solving both. It has been claimed by Kimura (1992) and Benbow (1988) that at the high end of Mathematical reasoning ability, males outnumber the females, even as much as 13 to 1 and that these differences are found before entering adolescence although the reason for the sex differences were unclear (Benbow and Stanley (1983) however, differences in problem solving ability do not appear until high school where females lag behind in some aspects of spatial abilities and in mathematics achievement at the top levels of math, but they are gaining on males in mathematics as a whole. It would appear that males are better at complex problem solving and females at computation.

This author posits that figure 7.7 illustrates why that might be. Females use Spatial Visualisation Ability to solve math related problems. As Voyer, Voyer and Bryden (1995) point out, spatial visualisation requires taking several steps to solve tasks that involve complex spatial information. Females use step-by-step procedures to solve arithmetic, at which they excel in the primary years and therefore apply step-by-step procedures for solving spatial tasks in their senior school years. Hyde, Fennema and Lamon (1990) state that females take more time to complete problem solving questions. They work through the problem in a step-by-step fashion and take more time to check their answers. Males however, do not perform as well as females at arithmetic in the primary years but when arithmetic is replaced with mathematics of which core components require spatial problem solving, males excel, especially at the higher end. It would appear that males are better at complex problem solving and females at computation.

Mental Rotation Ability is an important component of Spatial Visualisation Ability however females do not combine them with maths ability. Males however, combine Spatial Visualisation Ability, Mental Rotation Ability and Maths Ability together giving them greater potential to solve complex problems as found in Mathematics, Physics etc. How well a male performs at one will be reflected in the other two. Chapter four has already discussed the male biological advantage with regards to spatial ability and the influence of hormones such as testosterone. The influences of environmental factors are just as important for males as they are for females. A male who has the potential to be a mathematical genius will never reach actualisation if his environmental and educational needs are not met.

Males use their spatial ability to visualise a problem whether it be mathematical or navigational. By looking at the “whole” from a “birds eye” point of view, they are then able to extract relevant information and manipulate it accordingly, perhaps using mental rotation when three-dimensional manipulation is required i.e. chemistry or geometry problems. Sex differences will therefore be revealed in advanced mathematic subjects where female type strategies can no longer cope adequately.

Females use step-by-step processes just as in navigation where they tend to use Route Knowledge. The strategies are procedural and may explain why they outperform males at primary schools on arithmetic and elementary mathematics as well as language based subjects. As explained in chapter four, there is a left hemisphere dominance for most aspects of language as the left hemisphere is better at sequencing serially presented information i.e. speech sequences sounds in order to create words and language fluency is one of the critical areas differentiating the sexes. The female capacity for language has been explained by the assumption that the left hemisphere matures earlier for females than males. Therefore females rely more on verbal skills in problem solving, including non-verbal problems such as spatial tasks. For males, however, it is argued that the right hemisphere, specialised in spatial – perceptual processes, matures earlier than for females. Males therefore rely on physical movement and spatial perception rather than language skills when interacting with the world. In other words, if females use a more language based, procedural process to solve problems this would explain why there was no positive correlation between math

ability and mental rotation ability. It would also explain why, at the upper scale for math ability, there are fewer females than males.

Females however, it was argued, have a biological disadvantage with regards to spatial ability but with the correct resources and experiences, spatial skills can be learned to the point that differences in performance between males and females become non-existent or negligible except with regards to high mathematics ability. Males with poor spatial ability can of course also develop spatial skills but like the females, not to the level of those males with both innate and environmental advantages.

In this phase of testing the MRTs produced no differences in performance between the males and females suggesting that there was not a preponderance of males operating at the high end of mathematics ability. However, as the research is looking at the performance of individuals within VR, if participants had been chosen because of their ability to do maths then the results could not be generalised to the population at large. This is an important point to consider.

In this present research, approximately 400 people were tested on their mental rotation ability. The people were drawn from a population of Arts and Social Science and Science and Engineering students and staff at Abertay University, Dundee and Dundee College. Fifty-seven of these people were further tested on their ability to find their way around a virtual environment and to recall certain aspects of that environment. In the nine MRTs only two produced significant differences between male and female performances. There were no differences in

performance in the VR tests. These results could only generalise to similar populations of people.

A VR system that is, for example, used for training fighter pilots in combat manoeuvres where mental rotation ability is crucial will, by default, be training a different “type” of person from those used in this present research. Such people will possibly be “high sensation seekers” and, according to Zuckerman (1971), like risky or even periodically stressful vocations such as experienced by pilots. He also describes them as being dissatisfied and bored with routine, repetitious jobs that do not involve social interaction or challenging and changing activities. Sensation seekers are generally male and in recent years a specific gene has been associated with the sensation seeking personality trait. The gene produces D4, which is a dopamine receptor in the brain. High dopamine activity may be characteristic of sensation seekers. Other neurotransmitters may also be involved such as low activity in serotonin, which may account for a lack of inhibition and impulsiveness. Low noradrenergic reactivity could also account for the fearlessness of sensation seekers in risky situations.

There are few situations more risky than flying a Harrier jump jet into a combat situation and the pilots precision at flying, manoeuvring and targeting whilst tracking enemy pilot positions will depend greatly on their spatial skills, particularly mental rotation. Research has shown that pilots possess better spatial abilities for some tasks than the general population (Dror and Waag (1993).

Spatial ability, mental rotation ability and sex would have to be considered along with personality type when evaluating performance in flight simulators for fighter pilots. Such people are a minority group and females within such a group would be scarce. Further research into the type of female entering such a profession would be advantageous.

If VR is being used for training or educational purposes in areas such as engineering where spatially related subjects are required i.e. maths, calculus, engineering drawing and computer-aided design (Alias, Black and Gray. 2002), then it would be students in the high end of mathematical spatial reasoning who would be using the VR system. Females excelling in what is still considered a male dominated career might, just like the fighter pilot, be an atypical female with regards to inherited spatial ability, handedness, testosterone levels and experience. Those individuals, whether male or female, who are struggling in engineering or chemistry type subjects may well benefit from relevant spatial training as stated by Sorby and Baartmans, 1996 and Bodner (1989).

In other words, what the VR system is being used for will determine the performances to be tested. Where excellence in spatial ability is required, sex differences are likely to be found however training can increase spatial skills where Lohman and Nicholls (1991) have evidenced that women benefit more from spatial training than men. Where spatial ability is not a priority then gender differences will be unlikely.

7.8.2 General discussion

Once again the results were not what were expected. The male superiority at mental rotation was not evident on any of the three tests. It was true that males did score higher than the females but only marginally so and certainly not significantly so. The wire-frame and solid test did have the benefit of the third dimension being supplied by the 3D characteristic of the shutter-glasses. Larson (1999), as said before, could have explained the results on these tests because the 3D nature of these tests reduced the cognitive load on females who generally possess lower spatial ability and therefore find it harder to visualise three-dimensional objects. Once again, this explanation can be discounted as there were no gender differences with regards to the ROT, which does not benefit from shutter-glasses and according to Bodner (1989) and Sorby and Baartmans, 1996 produces consistent gender differences favouring males.

The ROT and the two 3D, computer generated MRTs were very different in that the ROT, as was suggested by Bodner (1989), might have been completed using Gestalt or Analogue processing whereas the wire-frame test may have needed Analytical or Propositional processing. The Solid MRT was possibly a hybrid of the two tests. It may therefore mean that what was important was not the gender or sex of the participant but whether or not they were a novice at spatial tasks. The different tests may have required different problem solving processes according to their complexity and the experience of the participant. Whatever the processes used, the tests showed that performance on one test could predict performance on the other two.

Interestingly, it was the solid test that was completed significantly faster than the wire-frame test. This may be explained by anecdotal evidence from the participants who said that the wire-frame shapes were too complicated in that there was too much information to “carry” in their “minds eye” and make sense of. The ROT was restricted to 10 minutes and it has been reported that females tend to react negatively to time restrictions, resulting in poorer performance on MRTs (Voyer, 1997). In this instance a time restriction did not appear to have hampered female performance on the ROT.

The surprising result was not that there was a significant positive correlation between the three MRTs but that there was a significant positive correlation between math ability and mental rotation ability for the males only. This was an important result and requires further investigation as it has been assumed that spatial ability and in particular mental rotation ability is an important factor underlying math success. Mental rotation was thought to be a mediator of gender differences on math tests (Casey 1997). These results indicated that the mathematically talented females did not perform significantly better on the MRTs than their less mathematically talented counterparts in the Arts. This in itself requires further investigation as teaching spatial skills may not necessarily be the answer to helping individuals with math difficulties.

The faculty to which a participant belonged did make a difference in that the Science participants significantly outperformed the Arts in all three MRTs, the Layout and Orientation tests. The math ability argument could have explained these results except it is now understood that, for this sample of participants, it

would only apply to the males. Males with low spatial ability, therefore lower math grades (Arts), performed significantly poorer than the male Scientists.

The results suggest that there are sex differences but not in performance but in the strategy used for solving problems. Experience also has to be taken into the equation in that there was a relationship between the number of hours spent playing computer games and the speed at completing the MRTs also with the accuracy on the Layout and Route Tests.

In the tests relating to the VE, there were no differences in performance between the males and females. The literature cited in chapter one, three and four all stated that there are differences in navigation ability, favouring males. Females, having poorer spatial ability, were expected to become disorientated when carrying out the way finding instructions. Disorientation would have led to taking wrong turns, back tracking and getting lost, such distractions would have been reflected in the length of time they took to complete the navigation instructions. This was not the case; there was no significant difference in the male and females timings. Further, males having superior survey knowledge to route knowledge were expected to be more proficient at the Layout and Route tests, again no significant difference. The Landmark test can be discounted at this stage. As stated before, there were no significant differences in the number of landmarks used by the participants to aid navigation. There was a flaw however, as participants were not necessarily recalling landmarks but instead, identification objects.

Although different navigation strategies may explain how the males and females were solving the VE tests, it does not explain why there were no significant differences in their performances. The answer might lie in the virtual environment itself. In this study a very neutral environment was used. It was neither masculine nor feminine. A house may be argued to be feminine or at least appealing more to females, however, the house was chosen because it was a familiar environment. All the participants understood the concept “house” and were familiar with houses, all were familiar with bathrooms, kitchens, bedrooms etc. The house was as complex as any maze used in many navigational tests. There were seventeen rooms of which six were bathrooms, some were on-suite and some were not. There were three floors, not all in the same orientation. There was a large garden, front and back, with the back garden not accessible from the front. As in the Alternative Route test, there were a number of routes available to a given target.

An important issue was the fact that the house lacked character, was very utilitarian in style in that there were neither masculine nor feminine touches other than in the childrens bedrooms. There were no ornaments, frilly curtains or chintz fabrics that might be described as feminine. By the same token there were no, electrical gadgets or male toiletries etc that could have been described as being masculine. In effect the house was neutral, appealing to neither the male or female taste. However, what was different from using a maze was that a house made contextual sense. For a female, finding their way around a maze suspended with fish or coloured shapes has no connection with reality, is irrelevant, bearing no resemblance to every day occurrences. It has already been discussed that

female preferences for computer games include relevance to everyday life and relationships.

There is a parallel here with Piaget and those who criticised his stage theory of intellectual development. Piaget was criticised for underestimating the age at which children exhibit the abilities associated with each stage of development. For example, Piaget believed that pre-operational children, those between the age of two and seven years, were “egocentric” in that they are incapable to take account of someone else’s point of view or perspective, they can only perceive their own. His famous three mountain task (Piaget and Inhelder, 1956), where a child is sat in front of a model of three mountains, one with a cross on the top, one with a cabin on and one capped with snow was used to show that children of this age group could not decentre. The child was asked to say what a small doll, which was placed at the other side of the mountain, could see. Piaget found that four year olds were not able to describe different viewpoints and tended to describe their own. Six year olds were more aware of other viewpoints but still tended to describe the wrong one. This, Piaget claimed, was proof that pre-operational children are egocentric.

Piaget’s conclusions were challenged by Hughes (1975) and McGarrigle and Donaldson (1974). Hughes tested childrens ability to decentre by devising a game involving a policeman doll and a boy doll. The idea was to move the dolls to different positions around two walls set up to form a cross shape. The child was asked to place the boy doll where the policeman doll was not able to see him. By involving the child in a game and using objects that the child was familiar with

and asking them to carry out a task they are also familiar with i.e. hiding, Hughes found that ninety percent of the pre-operational children were able to place the boy doll correctly, in that the policeman would not be able to see him. This showed that pre-operational children could decentre if tested in the correct way, in a way that is meaningful to them. It has been argued that young children understand tasks better when they are presented in natural settings, when the context is pleasant and interactive and when what is otherwise a difficult task is presented as fun and easy to do. Bryant (1974) argued that Piaget's tasks simply did not make sense to many of the children he tested and they looked for other cues to guide their behaviour. These other cues, such as the style of language used in the experimenters questions and instructions, were the reason for incorrect answers, not lack of cognitive skills. Bryant found that children under the age of five were capable of logic thought when they knew what was being asked of them.

By the same reasoning, it is the authors belief that if a female is presented with a spatial task that is meaningful to them and the instructions are explained in a precise and meaningful way, then they can perform as well as their male counterparts, up to a certain degree i.e. high mathematical reasoning. For instance, in the Rod and Frame Test which is a spatial test described previously, where the participant is asked to move a rod so that it is horizontal even when a square frame presented within it is tilted, males outperform the females. However, when the test is altered, in that a human figure is used instead of an abstract rod, no difference is found even although the participant still has to judge relative positions in space (Caplan, MacPherson and Tobin 1985).

In this present study, an abstract maze was replaced with a familiar concept that still required the learning of routes, orientation, visualisation, mental rotation and cognitive map development and consequently the females performed as well as the males. Further research should look at large scale environments that might cause more of a cognitive load for the female participants. It would be of interest to test male and female performances on two VR large-scale environments that could be described as stereotypically masculine or feminine, one for example learning the layout and navigation of a jungle war zone, the other the Trafford shopping centre in Manchester.

In all, the results of the three phases of experiments were not generally as expected. Many issues have been raised which need to be addressed but principally it was found that mental rotation ability or indeed lack of, is not the all encompassing answer to why it is that females do not perform as well as males within VR. The male superiority at spatial tasks has decreased (Voyer, Voyer and Bryden, 1995) or diminished to the point of being negligible (McIntyre, 1997) and the robust difference found in mental rotation tests has not materialized in seven of the nine MRTs conducted throughout this present study. Therefore, although there are innate differences between males and females, which might have come about through evolutionary reasons, it is not necessarily these reasons that are causing the problem. Motivation, practice and self-perception have been explored and in themselves, have produced interesting and challenging results, which are worthy of further research.

As suggested by Goldstein, Haldane and Mitchell (1990), the reason women might perform poorly on spatial tasks is more due to response tendencies, response styles or performance factors. This means females might prefer to work slower or omit rather than guess spatial tasks, due to lack of experience and/or poor self-confidence. It might also be the case that females solve visualisation tasks by using a non-spatial approach altogether (Burin, Delgado and Prieto, 2000), this in itself opens a whole new area of research. From an educational perspective, given that training improves performance on spatial tasks, especially for less able people and for females (Subrahmanyam and Greenfield, 1994; Kass, Ahlers and Dugger, 1998) it is important to know if both sexes need to be trained in a different way.

Chapter Eight

Chapter One Revisited

The main question that this study addressed was whether differences found in performance within Virtual Reality (VR) are innate i.e. they are due purely to sex differences in spatial ability or due to, at least in part, gender differences which come about through environmental factors. The findings, drawn from previous research stated in the first four chapters, showed that males have greater spatial ability due to evolutionary, biological reasons. The primary hypotheses therefore were that males would outperform the females on the mental rotation tests and the VE tasks. The results however, largely did not support the hypotheses and in fact showed that environmental and methodological factors have to be considered.

In chapter one several studies posited that the results of their research were due to primarily biological or innate differences between males and females. The main aim of this final chapter is to return to those studies to see if an alternative or a fuller interpretation could be put on their results in light of the findings and observations from this present body of work. In order to support a new interpretation it will be necessary to return to literature cited throughout chapters two, three and four and to include fresh research not already cited. Contributions to knowledge gained from this present research will be acknowledge when discussing each of the studies outlined in Chapter One

Chapter one stated that when using VEs, people have to learn and mentally represent the spatial characteristics of any computer-generated environment. It was explained that VEs are being used in many situations from training fire

fighters to diagnosing pathological conditions, to computer gaming. The individual characteristics and prior abilities of trainees and users have been given consideration since individual differences are already known to be a major source of variation in performance in real world spatial tasks. However, gender or sex differences, have had little attention, particularly concerning performance in a virtual world. The understanding that females have poorer spatial ability and in particular mental rotation ability has been used to explain why it is that females do not perform as well as males within VR. The results from this research have shown that males are not necessarily better at mental rotation as males only outperformed females in two of the nine MRTs and in the VE tests there were no significant differences between the male and female performances. These findings strongly indicate that factors other than innate ability have to be considered in order to explain the fact that females do indeed have poorer performances than their male counterparts when interacting within a VE. Chapter one highlighted some of those differences in performance.

8.1 Study One: Presence:

The first study referred to the subjective feeling of presence which Winn, Hoffman, Hollander, Osberg and Rose (1977) stated as being fundamental to enjoyment and to performance in a virtual world and that the role spatial reasoning plays in presence ratings is extremely important, with gender being a factor that effected presence ratings.

An immersive experience, particularly that experienced in VE, can be described as one in which a person is enveloped in a feeling of isolation from the real world. This feeling can be experienced when watching a film or when playing a video

game. The former requires no actual interaction whereas the latter requires the individual to have a high degree of interaction. When in a VE, if the individual has an actual task to perform, the experience of immersion and presence is increased (Patrick et al, 2000). Presence can be described as being the extent to which a persons cognitive and perceptual systems can be tricked into believing they are somewhere other than their physical location (Witmer and Kline (1998).

Winn *et al* found that spatial reasoning ability did not affect presence ratings for boys but low spatial ability girls reported lower presence than high spatial girls did. In fact, boys reported higher levels of presence than girls did. This does indeed indicate an innate or sex difference in that the male brain is specialised for spatial tasks and is affected by hormone levels i.e. testosterone, with there being an optimal amount for optimal performance. The fact that those males with lower spatial ability did not differ from the males with high spatial ability showed that they were all above some threshold needed for experiencing “presence” convincingly. Females, by necessity, possess less testosterone, on average, than their male colleagues, experienced less feelings of presence, with the low spatial ability females experiencing the least amount. These findings could be explained by Gouchie and Kimura’s (1991) study that found there is an optimal testosterone level which appears to be in the low to normal range with low-testosterone men being superior to high-testosterone men, but high-testosterone women performing better than low-testosterone women. These findings, they conclude, suggest some optimum level of testosterone for maximal spatial ability.

The ability to visualise is a spatial task and visualisation is needed for creative imagination. The right hemisphere, it has been argued, is where we “see” the whole and not the details that make the whole and is necessary for the role of imagination. Those who are considered to be right brain thinkers might be artisans, designers, physicists, architects, advertising executives, barristers, teachers or hairdressers along with authors, artists and poets. Such people are able to work in areas where they can put their imagination and creativity to effective use. The right hemisphere processes information holistically (Bodner, 1999) and as such is associated with imagination and spatial perception. It provides an overview of our environment and the objects that surround us.

Slater and Usoh (1993) suggested that VR has the ability to take the user to a virtual environment, leading to the “suspension of disbeliefs that they are in a world other than where their real bodies are located.” And Winn stated that boys might be more easily “fooled” into believing a VE is real whereas girls do not tend to be taken in so easily. The female brain, it is inferred, is less prone to flights of fantasy whereas males, with greater imaginal skills, are more prepared to be “taken in” by the virtual world, increasing their experience of “presence” which in turn has a direct effect on their performance.

A further innate difference, which has to be considered, is the role of peripheral vision. Peripheral vision plays an important role in learning the spatial layout of an environment (Ruddle, Payne and Jones, 1997, 1999) and women have wider peripheral vision than males. Optical flow in periphery vision benefits heading perception, particularly during active navigation. According to (Tan, Czerwinski,

and Robertson, 2003) optical flow helps females more than males as females have traditionally been described as landmark navigators. Females have an arc of at least 45 degrees clear vision to each side of their head and the same broad spectrum of vision above and below the nose. For many women, their peripheral vision is effective up to almost 180 degrees. Males have more “tunnel vision” therefore gender specific navigation benefits come from the presence of optical flow cues, which are better afforded by wider fields of view on large displays. Czerwinski, Tan and Robertson 2002) have found that having a field of view greater than 100 degrees is of no greater advantage to performance for either males or females. Interestingly, they believe that it is field of view and the presence of optical flow cues that interacts with female performance on navigation tasks and not spatial abilities as there male and female participants showed no differences in performance on a paper folding test (spatial task).

Sex differences can therefore explain the differences found between male and female ratings of “presence” due to hormone levels and hormonal influence over the developing brain. However, an environmental approach can also be considered in that Winn suggested that the differences in performance ratings might be because boys have more exposure to computer games and have learned skills for manipulating the interface. Chapter four has already pointed out that the Internet; computer software and computer games are typically targeted at traditional male interests such as action-related sports, games and computer programming. The study by Subrahmanyam, Greenfield, Kraut and Gross (2001) cited the CEO of Lucas Learning as admitting that their products were designed exclusively for boys. Subrahmanyam and Greenfield (1998) found that girls like

games that contain features that can be identified in their day to day play and reading tastes. Girls pretend play is based on reality, and involves characters that are either familiar or are at least realistic (Tizard, Philips and Plewis, (1976). Boys pretend play, on the other hand tends to be based on fantasy, containing action heroes with super powers and they favour settings that are non-realistic and larger than life.

Although anthropological studies of play would suggest that gender differences in modern societies are based on role modeling as suggested in the type of toys children tend to own, the fantasy content of their play is very different. As Tizard *et al* stated, girls enjoy realistic games that are imitative and home and people oriented. Their toy preferences are fashion dolls, mother and baby dolls, housekeeping toys such as vacuum cleaners and irons and furniture, clothing accessories and beauty items. Boys on the other hand, do indeed prefer imitative toys such as vehicles, constructions toys, sports equipment, workbenches and tools, models, electronic toys and weapons of aggression. Their game content is at a more unrealistic fantasy level with much more aggression and is generally directed away from the home. This cannot be entirely accounted for by role modeling as girls with CAH as explained in chapter four are far more aggressive in their play than their “normal” sibling sisters and have a greater tendency to play with boys toys.

8.1.1 Further explanations obtained from this present research.

The findings from research into game play reflect differences that can be explained as being sex differences. For males and females, it is their hardwiring

that leads to the different gaming preferences, the girls for social interaction and real life problem solving scenarios, the boys for competition, fantasy and aggression. However, with computer games aimed at the male market, it is little wonder that females have less experience with computers and the manipulation of interfaces. Girls are not encouraged to explore technology from an early age. Lack of experience with computers, joysticks, headsets etc will have an adverse effect on their subjective feeling of “presence” therefore the game player or user of a VR system will have to keep returning to “reality” in order to check what it is they are doing and if they are doing it correctly.

Those familiar with VEs can maneuver through the environments without giving conscious thought to the keyboard, mouse or joystick in the same way as an experienced driver does not consciously think about gear changes. The experienced gamer or computer user will not be hindered by thoughts of how to navigate successfully. Observations from this research showed that although there was no difference in the time it took the participants to complete the navigation scenarios in the VE tests, what was obvious was that during the practice and exploration time, many of the female participants had to be shown how to use the mouse and direction arrows on the keyboard to move through the virtual house. Some moved “crablike” as they used the arrow keys to turn right or left rather than the smoother turn of the mouse. A common occurrence was ending up looking at the ceiling or floor as the mouse movements were too exaggerated, similar to the novice driver turning the steering wheel too far in either direction. Such exuberant actions resulted in disorientation until the participant could work out whether they were walking on the ceiling, floor or

walls. Disorientation occurred when the participant moved too close to an object in the VE. If the object filled their field of view as would occur if they found themselves with their nose against the wall, for example, their view turned into one colour or texture, without any visual cue to allow them to determine their next navigation action (Marsh and Smith, 2002). The participants had to “pull back” until they could recognise other features that aided orientation.

The majority of females had to be shown how to open the doors whereas all of the males, except two, knew that one of the buttons or space bar had been set up to open and close the doors. Once the females had gained confidence with the interface, they were then able to explore the house and gardens. None of the males had to be shown how to move through the virtual environment therefore strategies they had learned from their experience with computer games was generalised to their exploration of the virtual house.

The feeling of presence can therefore be explained by both the nature and nurture argument. The male advantage in spatial ability gives them a head start when imagining themselves within a virtual environment. Environmental factors, such as the predominance of male, fantasy type computer games prevents females acquiring the experience required for learning spatial skills and developing computer literacy. As computer literacy is increasingly important for success in society and game playing is seen as a precursor for computer literacy (Subrahmanyam, Greenfield, Kraut and Gross (2001), it has been argued that the gender imbalance in gaming will have to be addressed.

8.2 Study Two: Learning-impaired students.

Another problem identified was that when allowing learning-impaired students to construct their own virtual environments, the experience was of greater value to “lower-functioning “ males. It has to be remembered that spatial cognition is fundamental for general cognition and is an important component in cognitive development. A spatial cognition disability may lead to difficulties in education and indeed to every day life as spatial ability and spatial cognition are needed for higher level thinking skills. (Gardner 1993)

Again, by emphasizing the use of the right hemisphere, Osberg, Winn, Rose, Hollander and Hoffman (1997) believe that using VEs help with mental rehearsal, introspection and visualisation. In effect, the students were being encouraged to be right brain thinkers, which ties in with Byrne’s (1993) theories of learning styles. Byrne advises that right hemisphere dominant learners are more concrete thinkers, using visual and tactile symbols whereby meaning is imbedded in their experience and he found that males tend to be such thinkers. The comprehension of science, using VEs, benefited the male students as they have the biological, hemispheric advantage, all be it they were described as being “low-functioning”.

These findings could also be explained by Gouchie and Kimura’s (1991) study that referred to optimal levels of testosterone for maximal spatial ability. The boys and girls involved in the study were of low general ability and were presumably out-with the optimal level although, crucially, the study does not state why the children had learning impairments i.e. was it through brain damage due to an environmental accident or due to a birth defect. Using a hands-on, experiential form of tutoring may have been more beneficial to the boys.

8.2.1. Further explanations obtained from this present research.

Having poor spatial ability may affect the boys ability to tackle complex problem solving such as is needed for mathematics or science but it would not necessarily affect other areas that differentiate the sexes, such as game preference. The relationship between spatial ability and mathematics, as found in this present research, has been clearly illustrated in the correlation tables in chapter seven. In figure 7.7 the diagram showed the possible influence of spatial visualisation on math ability, mental rotation ability and performance on VE tests. It illustrates how Maths Ability and Mental Rotation Ability overlap for Males but not for Females but Spatial Visualisation is important for solving both.

With reference to the learning-impaired students, the boys, once again, may have had considerable experience playing computer games and may have had a more enjoyable experience than the girls who were less familiar with computers and the manipulation of the interface or they may well have experienced other activities that are more spatial in nature than those of the girls i.e. block construction. In other words, although their biological advantage and potential had been somewhat curtailed due to whatever had caused the learning impairment, the hands on learning environment supplied by the VE had scaffolded the construction of skills on a disabled but none the less, biological foundation.

The girls, lacking both the biological and environmental advantages did not benefit from such a learning environment. The females were disadvantaged from the start and may well have benefited from a different learning style which is more in tune with their abilities i.e. simple book learning and one to one

interaction with their teacher, using words to communicate their thoughts and ideas and language to store meanings found in pictures and impressions which are considered to be more left brain activities (Byrns (1993). The difference in learning styles, particularly with reference to children with learning difficulties, is an important area of research. If VEs are being considered as a learning medium then it is important that gender and sex differences are considered. Females may well be at a further disadvantage if VR is used as a teaching medium purely on a new technology basis. It is therefore important to take into consideration the sex, background and prior experiences of participants before it is possible to come to any conclusions regarding performance and future research in this area is warranted. Once again Nature verses Nurture, innate versus environmental can not necessarily be separated.

8.3. Study Three: Mental rotation

Of importance to this study was the work by Buckwalter, Rizzo, Van der Zaag, Van Rooyen, Larson and Thiebaut. M (1999) who used tests of spatial rotation ability administered in a VE. Their results confirmed the reported differences outlined in chapter three, in that the males performed significantly better than the females in their paper and pencil test but in the VR test there was no gender differences. Females, they explained, find a 2D task such as the paper-folding task difficult to visualise whereas Larson (1999) suggested that the lack of gender differences on the VE task is because rotation ability within a VE adds the appearance of real three-dimensionality to the stimuli.

8.3.1 Further explanations obtained from this present research.

There is a discrepancy between the results of this present study and those of Buckwalter et al. and it would be prudent to try and understand why that might be. As already pointed out, in the nine mental rotation tests carried out in this present study, four were 2D and five were 3D. Only two of the tests showed significant differences in performance between the males and females. One was the “solid” 3D MRT which may indeed indicate sex differences in that the test might have been more complex than the “Wire-frame” or ROT tests thereby pushing female ability and skills to the limits. This is an important finding and is certainly worthy of research. The other was the 2D ROT in the self-perception test, but what has to be kept in mind is that the ROT produced no gender differences in the other two phases of testing. These results showed that the females performed as well as the males in three of the four MRTs where they did not have the aid of the third dimension as suggested by Larson. Something other than spatial ability was affecting performance and in this instance, self-perception may have had a crucial role to play. Larson’s suggestion cannot apply to the findings in this present research and other factors have to be taken into consideration such as who the participants in the tests were with regards to their general abilities, personality types, experiences etc which all may have had a direct effect on their performances on the spatial tasks. The sex of the participant will be a factor but perhaps not as important as it once was as gender roles are not as distinct as they were even twenty or thirty years ago, with experience making up for the lack of innate ability.

As VR is being used more and more for training purposes it is not enough to “blame” innate sex differences as the reason females do not perform as well as their male colleagues and research in the areas of self-perception will be crucial in order to level the playing field with regards to the training efficacy of the VR system. It would be a pity to throw the baby out with the bath water.

When Kimura’s (1992) study (chapter four, 2.7) studied the overall differences in spatial ability between males and females, she found that patients with damage to the right hemisphere scored lower scores for both sexes on the tests than patients with damage to the left hemisphere. Females were generally poorer than the males on a block spatial rotation test. Concerning damage to the right hemisphere, there was no greater effect in males than in females whereby it was expected that damage to the right hemisphere would be worse for males with regards to spatial performance. These results, she concluded, suggested that the normal differences encountered between males and females on such rotational tests are not the result of differential dependence on the right hemisphere but that instead some other brain systems had to be mediating the higher performance by men.

What those other brain systems might be could be explained by the study carried out by Shiina, Saito and Suzuki (1997) that set out to research which aspect of spatial ability is actually reflected in a participants scores in a Mental Rotations Test. They found that the differences in strategies found in the MRT are due not only to individual differences but also to the finding that experts solved Shepard and Metzler style MRTs by using simple and high-speed mental rotation that gave them a high score in the MRT. Novices produced low scores due to slow rotation

and the use of redundancy patterns. Their wide range of strategies and lack of unification was reflected in the number of mistakes that they made and the slowness of their mental rotation. This in turn ultimately affected how many questions they were actually able to solve. Emphasis was therefore placed on whether the participant was a novice or an expert not on whether they were a male or a female.

The study by Voyer and Bryden (1990) supported the notion that participants with high spatial abilities would show a right visual field advantage (left hemisphere) when performing a lateralised mental rotation task and those with low spatial ability would show a left visual field advantage (right hemisphere). The effect of practice was an important factor and they found that different patterns of visual field asymmetries found in participants with increasing levels of spatial skill provided support for the hypothesis that the right hemisphere has a greater ability to process novel stimuli, while the left hemisphere is superior at using familiar stimuli.

A participant with low spatial skills will probably have no or little experience (novice) with mental rotation, therefore the right hemisphere's specialisation in processing novel or complex stimuli would come into play explaining why low spatial ability subjects showed a left visual field advantage. In contrast those participants who have high spatial abilities and skills and were presumably familiar with tasks that involve mental rotation (experts) and consequently the left hemisphere, with its superiority at processing familiar stimuli, was favoured.

With regards to this present research, being a novice or an expert was a more important factor than whether the participant was a male or a female.

This is an important finding with regards to the way in which an individual processes information and can be seen in Bodner's (1987) work concerning the novice/expert argument. He considered the processes by which students use algorithms or very simple problem solving strategies to work routine exercises and the more complex process they use when faced with questions that are *novel* problems. He believes that propositional models of information processing may be used for novel and initially complex problems and analogue for familiar and simple problems. These finding would support Barfield et al's (1987) hybrid theory where they suggested a propositional account for mental rotation when the object was complex and analogue when more familiar.

To return to Kimura's (1992) findings that damage to the right hemisphere, produced no greater effect in males than in females may be because those patients with high spatial ability or spatial skills acquired through experience, were in fact no longer dependent on their right hemisphere. Needless to say, such an assumption requires further investigation. However, it would be true to say that spatial ability (innate) and spatial skills (environmental) are very difficult if not impossible to disentangle.

8.4. Study Four: Simulator/cyber sickness:

Massey and Drexler (1995) suggested that women experience more motion and SS than men and warned that as VR devices become more advanced and the feeling of "presence" is increased, females will continue to experience more side

effects. However, training mental rotation skills should help eradicate SS (Parker and Harm (1992)).

It was discussed in chapter one that there is an innate difference in FOV, in that females have a wider FOV (Czerwinski, Tan and Robertson 2002) and that FOV was the major determinant of SS (Seay, Krum, Hodges and Ribarsky 2002) with females having increased incidences of sickness (Kennedy, Lanham, Massey, Drexler and Lilienthal 1995

The use of HMDs usually means that there is a considerable reduction in FOV. In the real world, the horizontal visual field of view (HFOV) extends to just over 180 and the binocular field, where the two monocular fields overlap, accounts for about two thirds of this value (120). If an inexpensive HMD is being used, such as the Virtual i-glasses, the HFOV is reduced to as little as 30 degrees (Howarth and Costello, 1997)

In terms of the effect movement on the screen has in inducing the impression of bodily movement through visual information alone, the size of the field of view is extremely important. Peripheral vision plays a dominant role in convincing the body that movement is occurring, a fact that is well known to manufacturers of simulators such as I-Max cinema.

A more environmental interpretation of SS susceptibility was found in Biocca's (1992) literature view that also stated women are more susceptible to motion sickness but that this may be more due to males under-reporting susceptibility in self-reports.

Costello and Howarth (1997) review a number of problems with the VE systems that may induce nausea and must be considered environmental. These problems include flicker that refers to the frequency with which images are regenerated on the displays and has been linked to incidences of photo-epilepsy and visual lag that occurs when a user carries out a head movement. When operating in the real world, a head movement results in an immediate compensatory eye movement or a change in the retinal image. This synchronicity affords the brain to distinguish between the movements of the head and eye and the movements of objects. However, when using a VR headset, there is a delay as any information relating to head movements has to be first analysed and then the image on the screen has to be recalculated. Confusion arises when any reflex ocular movement, which occurs as a result of a head movement, actually occurs before the image on the screen has had the chance to be updated.

An interesting study into ethnicity looked at the effect of visually induced motion sickness amongst women from Chinese, European-American and African-American origins. The Chinese women reported significantly more nausea and other symptoms of motion sickness than either of the other groups, which did not differ from each other. They found that Chinese women are hyper-susceptible to motion sickness. Two explanations were given, the first was environmental in that the Chinese women had only been in America for less than three years, therefore may have cultural reasons for not being as experienced with computers, gaming and VR as the other groups. The other reason was innate or genetic, due to central catecholamine release. Whatever the reason for simulator sickness, it will

decrease over time as a tolerance is built as well as developing adaptive behaviours to avoid sickness (Uliano, Lambert, Kennedy and Sheppard, 1986).

8.4.1 Further explanations obtained from this present research.

Once again, the major problem of nausea that many, primarily females, suffer from when experiencing VR can be explained in both innate and environmental terms. With regards to this present study, seven volunteers had to withdraw from the VE component of the tests, as they became nauseas during the time they spent exploring the virtual house. Six of the volunteers were female whose symptoms ranged from dizziness to the onset of nausea; they abandoned the exploration as soon as they felt unwell. The male volunteer fared the worst as he later admitted that he did not want to say that he was feeling ill, he said it was “ a man thing”. He persevered well into the navigating scenarios before finally abandoning the tests, consequently feeling unwell for the rest of the day. It is possible that experimenter effects have to be considered with regards to interpreting results as in this scenario the male participant clearly did not wish to embarrass himself in front of the female experimenter.

The author of this study, both a female and new recruit to computer games and virtual environments, suffered nausea and head aches during the initial stages of setting up the experiment. Fortunately, the feelings of nausea dissipated with practice and experience. Strategies she used for avoiding feelings of nausea was also evidenced in the participants who felt symptoms of nausea when going down flights of stairs in the virtual house, they quickly learned to close their eyes for the duration of the descent.

Another important environmental contributor to SS is flicker sensitivity caused by the 3D toggle system and needless to say is an environmental/nurture issue.

8.5. Study Five: Transfer of Spatial Knowledge:

The mental rotation findings are important when considering the next problem in that the transfer of spatial knowledge in virtual environment training has also found robust gender differences in training effectiveness of VEs in favour of males. (Waller, Hunt and Knapp 1998). The participants were asked to apply route and configurational knowledge in a real-world maze and their results showed that female performance on virtually all tasks tended to be poorer than that of males.

8.5.1 Further explanations obtained from this present research.

Tasks used in this present study showed there were no significant differences in male and female performances in the Alternative Route, Layout and Visualisation tests. This study required the participants to use knowledge they had learned regarding the spatial arrangement of the house and gardens. They had to be able to successfully recall, visualise and draw the layout of the three floors and the routes that interconnected rooms, corridors, floors and gardens. They also had to be aware of orientation and direction whilst visualising themselves within the VE. There were no significant differences in male and female performances.

Again there is a discrepancy between the findings of this present research and those found in the literature review. An answer to why this should be may be found by looking at a test for measuring the transference of spatial knowledge. Typically a maze is used, either real world or virtual or both. Often the maze is

hung with abstract shapes for landmarks or the participant is able to walk through walls (Marsh and Smith, 2002). In the case of the Waller *et al's* study, participants were asked to navigate a 3D maze hung with swords, guns, balls and violins used as landmarks to aid navigation. It has already been established that females prefer games that relate to real-life, real events and real people and that they see computers as tools for creating, affording flexibility, allowing the ability to share ideas and as a means for getting a job done (Rabasca 2000). A maze filled with abstract masculine type symbols has little appeal to the female, ranking the task as novel but irrelevant to real life, therefore the motivation to attend to directional cues or route information may be decreased. Motivation can effect performance and not always in an expected direction as was evidenced by this present research which showed that the participants in the group that received **no** incentive to win performed significantly better with regards to accuracy than the group given the added motivation of a £100 prize. Interestingly and importantly, there was no significant gender difference in either group. The motivated group were faster but made more mistakes whereas the control group took longer but made less mistakes. The motivation to win £100 may well have had a detrimental effect on their ability to perform.

Attention and motivation would be important areas for further research as the optimal combination of both may increase performance on spatial tasks and the transference of knowledge. Sharp, Price, and Williams (1994) support the view that it is socio-cultural expectations of male and female roles and what is considered to be a masculine or feminine task that effects spatial task

performance. The maze test may be thought of as being a masculine task or game.

Males, however, are more competitive and may view tasks such as Waller, Hunt and Knapp's (1998) maze as a game, and a vehicle for comparing their skills with that of their colleagues. The violin could be classed as neutral, however the other landmarks were either symbols of destruction, as found in war games or were related to competitive sports. Motivation through competition may be an important factor to consider when interpreting Waller *et al's* results. Competitiveness was apparent in several of the tests conducted in this present study as most male participants wanted to know if they had scored more correct answers than their friend or if they had completed the tasks in a faster time. Only three females were interested in how they had performed. It was only males who, at the end of all the testing, wanted to know how they fared in comparison to all the other participants, most of whom would have been total strangers to them.

Interestingly, in the real world version of Waller *et al's* maze, the participants were asked to navigate the same layout but this time the landmarks were large letters of the alphabet. To the female mind, the author hypothesises that using letters makes more contextual sense, "turn left at B and head for D..." using familiar, linguistic symbols, which after all is what every street sign is comprised of and is a more real life occurrence. In this context there is a logical purpose, a task to perform and this is aided by the kinaesthetic appeal of physically moving through the maze rather than having to imagine actually being there or having to contend with cue conflict. It comes as little surprise that in the real world

condition, the females performed as well as the males. The use of appropriate symbols particularly with regards to navigational aids will need further research. Gender neutral rather than gender specific symbols should be considered long before the design stage of any software intended for gaming or training purposes.

An explanation for why there were no differences in performance in the VR tests in this present research was given in chapter seven. The house, it was explained, is a familiar concept to both males and females. Although there were more twists and turns, compartments and rooms than found in relatively simple maze tests, the females were able to recall routes and layouts and give directions as well as their male counterparts. The house environment made sense was true to life and there was no real reason that the task should be considered a game. The male participants however, very much saw it as a game.

In pilot runs it was a regular occurrence to have to stop the males from exploring the house before they were explained the instructions. Females always waited for the instructions before approaching the mouse and keyboard. Males also tried to “cheat” in order to cut down on time. This was the reason participants were asked to “tag” target objects in the timed way-finding scenarios in order to ensure that they had actually reached the target and not merely seen it from a distance. In order to “tag”, a right click on the mouse activated a firing instruction whereby a bullet would be fired at the target object leaving a bullet hole. Often, during the time a participant was given to explore the house and before they were told that there was a trigger option, the males had already discovered the trigger and used their bullet allowance by spraying mirrors with bullet holes or leaving their initials

in the walls. A number of the males also knew how to “reload” for a fresh supply of bullets, obviously transferring knowledge gained from their computer game experience. No female did this. As most of the males were game players, with varying degrees of experience, they were aware of the firing capability, only one female was aware. A number of males also enquired if there were “jump” and “crouch” options, indicating that they were experienced with the gaming interface. These observations showed that the males considered the VE as a game whilst the females viewed the test as a task to be done and waited for the instructions to carry out the task successfully.

The difference between using the house and the maze is context. Just as Piaget underestimated the cognitive abilities of pre-operational children by using test procedures that were alien to children or using language that had little meaning for them he obtained results that were not a true reflection of their abilities. In the same manner, it may be the case that many navigation style tests and methodology are simply not suited to females. This is an important criticism and should be followed with further research. As with Piaget’s tests, relevant testing procedures, taking full consideration of the tests themselves, the instructions given, terminology used, type of feedback and the target population particularly may well produce results that more accurately portray female abilities. To continue testing with what might be flawed methodology will hamper research, possibly resulting in incorrect training practices. This can be likened to Piaget’s influence on the education system where his findings led to a revolution in educational practices particularly at primary levels. Today’s thinking considers Piaget’s findings to be flawed and many educational practices are returning to strategies

used before Piagetian influences came to dominate education or they are taking on board practices first taught by Vygotsky and Bruner. It might be argued that childrens education has suffered for the past 30 years due to faulty methodology at the research stage; it would be unfortunate if research into VR training followed the same route. Needless to say, faulty methodology is a very important environmental factor to be considered.

8.6 Study Six: Navigation strategies:

It has been established that males and females have different navigating strategies with males being more accurate at building conceptual models of a given information space due to their greater spatial ability. Czerwinski Tan and Robertson (2002) have helped by providing wider fields of view on large displays thereby cutting down the amount of navigational information a female has to carry in her working memory. They said that providing wider fields of view on a large display means the cognitive task of building a mental model is no longer necessary and that landmark navigation, being the preferred navigating strategy of females, is optimised.

Using landmarks to aid navigation rather than the more complex geometry of survey knowledge developed by males may have been strategies that have evolved from our ancestors (Eals and Silverman 1994). This then would suggest that the differences in strategies are innate. Females did not need to evolve complex navigational strategies, as they did not wonder far from home. It is also possible that the female ability to multi-task would not have encouraged strategies that required costly cognitive map assembly resources. The early female had the tasks of looking after the children, making food, gathering berries, tending the ill,

skinning animals, curing leathers and perhaps growing small crops. While the men folk were out hunting they also had to protect the settlements from danger. A female then had to be able to do several tasks, often at the one time i.e. multi-tasking.

Siegal and White (1975) stated that the use of Route Knowledge or the use of landmarks for navigating, enables the navigator to reach a landmark from which they then can recall the necessary direction to take in order to continue their journey. Interestingly, it was noted by Barfield, Sandford and Foley (1988) that there were gender differences favouring males on the speed at which mental rotation was carried out, this, they suggested, may have been due to females being more successful at multi-tasking and this was reflected in the strategy they chose for problem solving. The propositional model is more complex than the analogue model therefore requiring more cognitive resources and more suitable for focused problem solving than multi-tasking. Males on the other hand tend to be more single task focused or are “one tracked”. Using the Hunter-Gatherer theory of evolution, men developed a superior spatial ability because they had to go out on hunting expeditions, often for days at a time. It was crucial that they could keep track of where they had been, work out where they were going and importantly know how to get back. Hunting for game is a single, focused task not requiring the need to multi-task.

Computer games companies have recognised that games are traditionally male dominated as males are able to keep their minds concentrated on the task in hand. This they have put down to the male brain being more lateralised, the female brain

with the larger corpus callosum has two hemispheres constantly communicating with each other and they are therefore more aware of things happening around them while doing a specific task. This may indeed be another reason why females do not perform as well as males within a virtual environment especially if it is a fully-immersive VR. Being aware that the world is going on around them while they are encased in a headset could be stressful or disconcerting and would detract from creating a feeling of “presence”. A semi-immersive headset would mean that the female has to concentrate on the task whilst also being fully aware of the environment around them, almost guaranteeing that the task was not receiving their fullest concentration.

This was an observation noted by Byrne (1993) when using VEs for educational purposes. Byrne observed that the boys tended to stay on task and worked quietly on their computers whilst the girls on the other hand, while working on the computer, also made up songs and dances or would get out of their chairs to spin around and giggle in between creating objects. Females needed social interaction. Training using VEs will have to address these differences in learning styles. Females may become bored and distracted if they have to spend a great deal of their training time in a virtual environment.

Rubinstein, Meyer and Evans (2001) stated that teaching people to multi-task in the work environment is less efficient, as managing two mental tasks at once reduces the brains resources for either task. However, there are many anecdotal evidences to support the notion that in both the workplace and the home, females are more adept at multi-tasking than males.

The difference in navigational strategies would therefore appear to be innate with females evolving a simpler method of navigation as they had multiple tasks to do at any one time. However, it has to be pointed out that the neuroscientist Roger Gorski, has stated that there is no neurological evidence for female multitasking superiority, females multi-task simply because they have to! (Shellenberger 2003) This then indicates an environmental or cultural difference between males and females meaning that a male can learn to multi-task and use simpler problem solving strategies such as analogue processing in the same way that a female can learn to be single-minded and focused on a task, affording to use the more complex and resource heavy propositions. Indeed, in William's (1993) rat study he too found that female rats have a greater tendency to use landmarks in spatial learning tasks however, if no landmarks were available the female rats used geometric cues. In contrast, males did not use landmarks at all, preferring geometric cues almost exclusively.

The choice of navigational strategy is not necessarily fixed by the sex of the individuals, as the two types of strategy, route or surveyor, are not completely independent. Lawton (1996) found a correlation between the two strategies indicating that individuals do not rely exclusively on one type of strategy. Instead, she stated, individuals can switch depending on the context just as demonstrated on other spatial tests such as mental rotation. As already discussed, depending on whether a task is novel, complex or familiar will determine the strategy used to solve the task. Whether way-finding or mentally rotating, individuals will switch strategies as they gain familiarity with the environment or task. In the case of way-finding, as route knowledge precedes surveyor

knowledge (Siegal and White, 1975), it can be assumed that an individual will shift from a route strategy to a surveyor strategy as the environment becomes more familiar to them. Lawton (1996) suggested that an individual who generally uses a route strategy for way-finding might switch to a surveyors strategy when there is little or no route information. Likewise, if an individual generally uses a surveyor strategy, they will switch to a simpler and less cognitively loaded route strategy if the environment has many landmarks and route information. How quickly an individual makes that transition will depend on their spatial ability and skills learned through experience.

Interestingly, Lawton also found that females in her way-finding study reported higher levels of spatial anxiety than did the males, that are anxiety about performing way-finding tasks. In the mental rotation test in this present study that manipulated self-perception, a number of female participants made the comment that being told females were better than males at MRTs made them feel anxious and that this knowledge might have affected their performance. Lawton (1994) found that there was a positive correlation between non-directional strategies for way-finding i.e. route knowledge favoured by females, and spatial anxiety but that for surveyor strategies there was a negative correlation. However, it could not be determined if inaccuracy in directional knowledge directly influenced spatial anxiety or if it was the case that being anxious reduced the individuals ability to use directional cues and therefore increased there need to use external help such as landmarks to aid way-finding. Anxiety might therefore be a factor that deserves further research particularly if skills and strategies could be trained that would effectively reduce anxiety and improve performance.

8.7 Study Seven: Place learning ability

With regards to place learning ability Astur, Ortiz and Sutherland (1998) found a sex difference in the Virtual Morris Test. When females were deprived of local cues they found it difficult to locate a hidden platform submerged in the water. Local cues can be tactile, olfactory or visual cues that aid place location. Males use more distal cues that mark out an environment, such configurational knowledge of an environment allows the individual to localise places that are not perceptually available and this in turn serves as reference points in determining position in an environment. According to Garling, Lindberg, Carreiras and Book (1986), such a reference system would vary depending on the degree to which they provided fixed points that could be referenced from anywhere within the environment. Local references are used in specific areas of the environment so that when an individual relocates to a different area, they will have to reorient to a new set of reference points.

For instance, using the female Gatherer as an example, she may need to know where she has hidden a particular food store. It may not be far from home but has to be found amidst an array of woodland, grasses and shrubbery. To locate the hiding place accurately she will need to recognise perhaps a fallen tree or a mound of stones that marks the spot. The male Hunter on the other hand needs to recognise distinct geographical areas where it is known that game is to be found. This area may be many miles away and he cannot rely on local cues which may alter according to the seasons i.e. trees shed there leaves altering there shape or boulders can be hidden according to the weather i.e. snow may cover landmarks making them indistinguishable from other forms. Distal cues such as mountains

or rivers and a surveyors knowledge of the environment would be of greater aid to navigation for males.

Lawton (1996) stated that both surveyor and route strategies would be equally successful in most way-finding situations. In the Orientation test, where no differences in performance was found, either route knowledge or surveyors knowledge could have been used to answer the questions. Participants could have either “pictured” themselves looking down on the environment and making their directional judgments accordingly or they could have mentally repositioned or re-orientated themselves within the environment using a new set of reference points at each position as dictated by the question.

Having surveyor knowledge of an environment is beneficial when the individual deviates from a specified route as in the timed way-finding test. Surveyor knowledge allows for a quick mental reassessment of fixed reference points in order to re-establish position within an environment whereas the individual using route knowledge or local cues would be more likely to become disorientated. Becoming disorientated or lost would result in participants in the way-finding test taking longer to carry out the instructions. As there was no difference in male and female performances, with regards to time, it might have been possible that all of the participants were using survey knowledge. Further research would require the researcher to count the number of wrong turns taken by the participant or how often they had to stop in order to find there bearings in order to ascertain what kind of strategy was being used.

Gron *et al* (2000), believe that behavioural sex differences in navigation performance are due to different neural substrates for spatial cognition. Women coped with the Virtual Morris Test by using a right parietal and a right prefrontal area, whereas men used the left hippocampal region. This they suggested might be related to differences in the processing of spatial information as women rely predominantly on landmark cues and males use both geometric and landmark cues (Sandstrom, Kauffman and Heuttel, 1998). Activity in the prefrontal area in the female group reflected the demands of the working memory while holding landmark cues on-line and keeping track of the routes taken. For the males, left hippocampal activation represented the neural substrate that enables males to process multiple geometric cues. Male-specific hippocampal activity may also demonstrate the males reliance on the use of episodic memory information in navigation as the hippocampal formation functions in episodic memory. In other words, the female navigates from landmark to landmark without necessarily having a mental map of where it is she is going or has just been, the male uses stored memories of personal events in his episodic memory, these may include factual knowledge such as the context of the event i.e. the day or the situation.

Again, an innate sex difference can explain the differences in navigational performances between the males and females. In this present study distal cues were not necessary for successfully navigating the VE and may indicate why proximal cues were used in the way of landmarks. As stated previously, in this study many participants listed objects such as the contents of the childrens bedrooms as landmarks. These objects included posters, pennants, toys etc. that could be classified as proximal cues as they were used to identify individual

rooms and were not used as navigational aids *per se*. Should this study be replicated, participants would have to have a clear understanding of the term “Landmark” in order to avoid ambiguities and inaccurate results.

Although Gron *et al* (2000), can explain behavioural sex differences in navigation performance by referring to the use of different neural substrates for spatial cognition, this does not mean to say that these detected differences dictates the strategies used by the sexes but instead may reflect the strategies favoured by the genders. It might be that the type of instruction given to the participant in a way-finding task will determine the strategy used and the amount of attention that is given to environmental information. This concept was indeed supported by Baenniger and Newcombe (1987) who found that gender differences in their way-finding tests were eliminated when the participants were given specific instructions. The type and wording of the instruction was important as it was used as a guide to the kind of information that had to be attended to and stored for later retrieval. Instruction then is crucial to any VR system being used for educational or training purposes. The type of instruction will have to be precise in its nature if the system is to get the best results from its users. Research into the understanding and dynamics of instructions would be advantageous for any training or teaching medium.

8.8. Study Eight: Transference of spatial knowledge

Finally, studies of the transference of spatial knowledge from a VE to the real world have shown that gender significantly influenced the accuracy with which participants made pointing judgements with males being more accurate. It was found that females became severely disorientated in a virtual maze with half of the

female participants making bearing (pointing) errors in excess of 40 degrees for both the virtual and transfer phases of the experiment. By now it is undeniable from the foregoing discussion that males generally have more accurate navigating skills and abilities and that these differences are innate. However, as Waller, Hunt and Knapp (1998) mentioned, there was a marked difference in estimating directions in their study depending on whether a joystick or finger was used for pointing, suggesting that interface proficiency has to be considered before using measurements acquired in a VE to draw conclusions about an individuals knowledge of a real-world space. Once again, lack of practice or experience with computers and associated technology may be hindering females in their performance within VR.

Parker and Harm (1992) also suggested that giving people practice with mental rotation tests would help them to adapt more quickly to many virtual environments by increasing their ability to adapt to the stimulus rearrangements produced by VEs. Practice in other words would improve spatial skills i.e. mental rotation, which in turn would aid manipulation of the VE and movement within it.

8.8.1 Further explanations obtained from this present research.

It was clear from the results obtained in the VR tests that the females were just as competent as the males in transferring the knowledge they gained from their experience within the virtual house to the paper and pencil tests. Females were just as accurate as their male colleagues in recalling the layout of the three floors of the house. The females were just as accurate as their male colleagues with regards to visualisation, orientation and giving directions. As pointed out

previously in this chapter, there is much more to differences in performance than purely gender or sex differences. Motivation, prior practice, self-perception, culture, relevance, context, use of symbols, type of instruction, IQ, background etc. etc. all have to be considered before it is possible to give a full explanation as to why certain samples of the population perform differently from other samples.

8.9 Project achievements, contribution to knowledge and future research.

The aim of this study was to investigate whether or not the gender differences found in performance within Virtual Reality (VR) are due purely to innate spatial ability differences or due to, at least in part, environmental factors. The project objectives were achieved in that the literature review showed categorically that sex differences give males the advantage with regards to spatial ability however the results from this research have shown that environmental factors are crucial determinates of performance that should not be overlooked or underestimated. The evidence produced shows that innate and environmental influences cannot be separated and that what cannot be ignored are the environmental factors that affect performance especially with regards to individuals with low spatial ability whether they are male or female

Of crucial importance is the finding that sex or gender differences are not necessarily as important a factor as was once believed. Perhaps thirty or forty years ago such a belief was justified but society has changed. Females are making up for lack of innate ability with experience and the development of skills. Gender roles are becoming more blurred and parents are more prepared to encourage their daughters into more male dominated disciplines. A major problem

however, is that the behaviours of a lifetime, indeed since the beginning of mankind, will require evolution to speed up its processes if changes in cognitive patterns are to keep up with changes in society.

In order to aid evolution and to ensure that females or indeed anyone with spatial abilities that require a boost, the producers of VR systems and researchers into performance within such systems will have to look beyond sex differences in order to improve their software. This body of research has shown categorically that something as simple as practice and often minimal practice, can eliminate performance differences.

8.9.1. Summary of main findings.

One of if not the most important findings in this present research was the lack of difference in spatial performance regarding the sex of the participant. In the ROT and 3D wire-frame MRTs, there was no significant difference regarding accuracy and no significant difference in reaction time in the wire-frame test. These results may indicate that the MRT, once a robust test of sex differences in spatial ability, has now gone the same way as other spatial tests whereby the differences are either negligible or non-existent. These results are challenging as they stand against the general belief that males have greater spatial ability than females and that these differences are innate. A changing society and development of spatial skills has gone a long way to reduce and indeed eliminate the gap in performance. However, it has to be said that in the “Solid” MRT, although the males were slower than the females they were significantly more accurate than the females. The “solid” test was a more suitable test to use in a 3D environment, as shading is

an important depth cue that is vital for the perception of depth in a VE. The fact that females found this task more difficult, in that they performed significantly poorer with regards to accuracy, than their male colleagues, requires further investigation in order to find out why. It is perhaps the case that being presented with a solid 3D shape to manipulate forced the females to use mental rotation rather than some other strategy to solve the problem. Task complexity therefore is a worthy area for further investigation in order to understand the cognitive demands of visualisation and mental rotation. The male advantage in spatial ability may indeed have outstripped spatial skills when dealing with a more complex spatial problem as encountered in the solid 3D MRT. Nurture therefore can stretch the female elastic band to its furthest point whereas the male elastic band is bigger in the first place.

The second phase of testing looked at motivation, self-perception and practice. The motivation MRT, instead of showing a marked improvement in performance, in fact showed that offering a “prize” had a negative effect on the participants. By adding a competitive edge to the task may have detracted from attention and problem solving strategies, instead guesses or gut-feelings may have been substituted for the sake of time. Despite the prize and timing factor, there were, once again, no significant gender differences in performances.

The results also showed that Motivation, in this case money, did not produce any significant difference in performance between the control group and the “prize” group. This was a surprising result and should be of interest to any work place situation whereby employees are rewarded for their work by way of their pay

packet. Trainees may not be encouraged or motivated to learn just because there is the incentive of a good salary. However, it might be the case that in this particular test the extrinsic motivation of money was equaled by the intrinsic motivation to do well in the test.

Future research should look at motivation and attention, i.e. do varying types of motivation encourage participants to attend to the task more conscientiously therefore encouraging improved performance. Intrinsic and extrinsic motivation, with regards to training, education and game play within VR are important factors to understand and manipulate. An individual who is intrinsically motivated to learn will perceive learning as enjoyable, a challenge rather than a hurdle to be crossed. Learning styles will have to be borne in mind as those who prefer social situations such as traditional classroom learning will not necessarily be motivated to learn within VR, therefore psychological types will have to be considered both in educational and training spheres.

VR in the classroom situation normally refers to non-immersive or desktop VR and is used in situations where it is advantageous to simulate a concept, which is otherwise difficult to visualise. It is therefore desirable that the system increases the students motivation by increasing the experiential quality of their learning (Mills and de Araujo, 1999). An increased feeling of presence and the encouragement of exploration can aid motivation. Research is therefore required into motivation and its effect on learning and how the software itself can be enhanced to encourage learning. The goal of the designers should be to create systems that can exploit the visualisation of the world or environment it is

supposed to portray. The use of aids, navigational tools, spatial maps, textual contents lists, avatars etc. should be explored in order to encourage a students or trainees desire to explore and learn through constructing their own worlds or ease of navigation through a training package.

In game play, both intrinsic and extrinsic motivations are necessary for the continuation of the game. If a gamer is not intrinsically motivated because they find a game boring or if they are not extrinsically motivated via peer admiration or being able to place their name on the highest scorer list, then they will not be motivated to buy expensive computer games which is after all, what the marketing companies want. VR training for career purposes must consider motivation. If employees are better motivated to learn in a real life situation rather than using a virtual simulator then cost effectiveness comes into play. If VR is employed for safety purposes such as training bomb disposal or fire fighting crews, then research into ways of keeping individuals motivated and on task will be crucial

In the “practice” experiment there were no gender differences, perhaps indicating that the type of subject that all the participants were taking i.e. psychology, is one that does not require excellence in spatial skills therefore males with poorer spatial ability and less practice in spatial activities, are attracted to such subjects. This then might explain why no gender differences were found. What is of importance to this present study is that everyone, males and females, improved significantly between trial one and trial three. This however does not mean necessarily that spatial ability improved generally but it certainly improved on this specific task.

The results of the “practice” experiment showed a significant improvement in performance between Test 1 and Test 3 although there were no significant gender differences across the tests. As was stated this may well reflect the fact that all of the participants were psychology students and as such may have had poorer spatial ability than might have been demonstrated by math students. Their performance had nothing to do with being either male or female. It does have to be noted however, that the males “practice” test did improve greatly between tests 1 and 2 and although initially poorer than the females in test one, were in fact better than the females by test 3 although not significantly so. Practice, helped by an innate all be it poorer spatial ability, may have accounted for the male improvement. These results show that the participants taking part in testing procedures have to be chosen with very great care. The sex of the participant in this particular test was not the important factor; the fact that they were all psychology students was the crucial issue.

For the “self-perception” test the hypothesis was supported in that self-perception did have a significant effect on performance but not in the way the author assumed. Rather than improving performance, informing the female participants that they were better at spatial tasks than males, appeared to have a negative effect on their performance. The males in the control group not only produced the highest mean score but they also did significantly better than the males in the group where the boys were told that they were better than girls at mental rotation tests. In this test it is possible that being told you are supposed to be good at something can create anxiety that in turn can affect task performance. This anxiety will be heightened if the participant already holds the belief that they are

not good at this type of task. Interestingly, it was only female participants in the group where the females were told they were better at MRTs than males, who commented that this information made them feel anxious and might have gone some way towards explaining their poorer performance. As Beyer (1990 and 1977) suggested, negative self-evaluations may have damaging behavioural consequences. Research should therefore concentrate on how to create positive self-perceptions. An individual who views their abilities positively has a strong advantage when it comes to learning and interacting with society generally. One approach is to encourage females from the youngest age to engage in spatial tasks so that a negative self-perception cannot be formed and spatial skills can be gained. By encouraging females to take a greater part in the world of computers and games would go a long way towards aiding this problem.

Although the results of this present study revealed no significant differences in performances between the males and females in the VE tests, it was obvious from the literature that differences are being found. In the case of sex differences, more should be done to create gender-neutral interfaces. In this study, as was explained, the virtual house was gender neutral and this in itself may have contributed to the fact that there were no significant differences in performance between the males and females in their way-finding, orientation and visualisation tests. Institutions where it is not possible for the training environment itself to be neutral, such as in a military scenario, then known sex differences should be considered. A known navigation strategy difference is that concerning the use of landmarks, the use of meaningful, salient landmarks rather than arbitrary symbols would reduce the load on cognitive resources and would decrease any reliance on

the need for spatial presence, especially where mental rotation ability is concerned. According to Siegal and White (1975) landmarks should be highly visible, easily recognised, stationary and visible within a 360-degree field of view allowing users the ability to look around the VE in all directions. These recommendations are primarily aimed at the female strategy for navigation but would be of benefit to all users. More male directed navigational aids would include cues for Euclidean distance and direction.

During the VE exploration in this present research, a number of participants commented that they felt they were flying rather than walking around the VE. All of were new to VEs and had either never played computer games or had played only a few times with no great interest. The feeling of flying, especially when going up and down stairs and going around corners was likened to being on a roller coaster, leading to momentary giddiness and disorientation. Several participants stated that they soon learned to shut their eyes briefly or to slow down when they thought they were approaching areas that might make them feel nauseas. Others also commented that when looking for landmarks in order to get their bearings, they used the mouse to “turn themselves around” again creating the feeling of “burling around”, it would have been wiser to use the direction arrow keys which are slower but less likely to induce dizziness.

An interface that could offer the user the ability to look right, left, up or down in a steady movement would decrease their need to rely on mental rotation ability. Fully-immersive VR can of course offer such a facility but as these systems are prohibitively costly a helping hand should be offered to the other forms of VE i.e.

Desk-top or semi-immersive. The feeling of flying around the visually presented terrain is not a natural approach for human navigation and it would be of benefit to all users if the technology could aid users to navigate a virtual world if it is presented in ways that most closely reflect how typical users navigate the natural environment.

A further observation from the timed navigation test in this study was that in the scenario where the participants were asked to take the quickest and most direct route to the 6 bathrooms in the house, they had difficulty remembering which bathrooms they had already visited and which were still to be found. In other words, they had to carry a mental map of the house, memorising where they had been, which bathrooms they had found, where had they still to explore whilst at the same time thinking about where the other bathrooms could be. The introduction of meaningful textual information at this point would have been advantageous. Perhaps a list of the bathrooms already found could have been made available, if the participant had so chosen, thereby cutting down on the amount of information they had to carry “on-line”. Textual information on an otherwise visual interface would benefit all users no matter what the context of the VE. Textual summaries of any visually presented information decreases the burden on the visual channels to supply all necessary information to the cognitive mechanisms needed for interpreting and understanding the presented information. Additional sensory help could have come in the way of bells or buzzers that would have alerted the participants to the fact that they had made a wrong turn. This technique could be used in training VEs to alert participants to danger, time running out etc. In other words, by using multi-modal cues for augmenting

information that is otherwise presented via visual sensory channels, can only be of help to all users.

It was also noted from the “bathroom” scenario, the bathroom that was the hardest to recall and find was the one to be found in a room off the kitchen. A possible explanation might be that in the UK it has been, until recent years, illegal to have bathrooms immediately adjacent to a kitchen, for hygiene reasons. It might be that participants were using a mental script of a typical house, using their knowledge of a typical house layout and where a bathroom might be expected to be found, that the bathroom was in an unexpected place could explain why it generally was the hardest to recall or find.

A great deal of research has already gone into the way that users of VEs move themselves around particularly in studies of navigation (Templeman, Denbrook and Silbert, 1999; Darken and Silbert, 1996; Ruddle, Payne and Jones, 1999). There has even been research on how users avoid obstacles in a cluttered VE (Ruddle and Jones, 2001) but there has been little or no research into environmental factors that effect performance such as lack of practice and self – perception. The effect of practice has already been discussed and the self-perception test produced a mixed assortment of results that demand further investigation. The results in fact confirmed that self-perception does have an impact in both decreasing and increasing performance.

8.9.2. Encouraging Females to be part of the Computer Revolution.

Why girls have less computer experience than boys can be linked to sex differences in that the nurturing role of females is not catered for in the world of

computers and gaming. The nurturing role encompasses the need for social interaction and games that involve skills and abilities that appeal to girls. The success of the “Tamagochi” type toy amongst females is an indicator towards the type of gaming environment females are interested in. Although it is not suggested that all games should contain nurturing roles, the lack of female orientated games means that females are not encouraged at the initial stages to take part in the computer revolution and to be as computer literate as their male counterparts.

The lack of presence can to some extent be explained by the fact that females are not accustomed to the rules of game play or are not used to manipulating interfaces because they have not been encouraged to interact with computers. Their lack of ability to manipulate the interface was evident in the exploration of the virtual house as discussed previously. The male participants displayed an understanding of how to get about an environment that the females lacked. This is a problem that is sorely in need of solving in order to level the playing field as far as computer literacy is concerned. Lack of practice and self-perception are intertwined factors that, in this study, have shown cannot be ignored. If an individual, whether they may be male or female, lacks practice in any area then their self-perception and feelings of anxiety concerning their performance will invariably be negative. If society encourages a negative stereotype then the poor self-perception is compounded. In the world of computing, negative self-perception and lack of practice will have to be addressed, as the use of VR for educational and training purposes will leave females at a disadvantage.

The issue of practice can be resolved to some degree by introducing educational software into the classroom that is suitable and attractive to both males and females. It will be necessary to combine the knowledge of scientists, psychologists and educators with that of game and educational software developers. Already there is some head way with the introduction of E-Gems (Electronic Games for Education in Math and Science) that seeks to increase the proportion of children of primary age who enjoy learning by mastering and using underlying concepts of math and science. There is another serious side to computer games technology in that computer games are not just about leisure and entertainment. Examples of this are evidenced in the work being undertaken by IC-CAVE at Abertay University in Dundee and the MediaLab in Dublin. Research by IC-CAVE (International Centre for Computer Games and Virtual Entertainment) together with the BusinessLab in Aberdeen, "play2win" - investigates the application of computer games to business and organisational learning.

Further research by IC-CAVE uses observational and empirical data from British and Japanese teenagers and adults. Of interest were cultural variations in game playing habits and preferences, across the age groups. Data were reviewed in relation to intrinsic and interpersonal motivations and needs motivations and the outcome is a tentative model that illustrates and explains cultural variation in computer game playing.

The researchers have stated that their findings have important implications for usability practice and game design. They believe that by

carrying out usability testing of games with targeted players from different cultures, they can modify components of the games, fine tuning them to optimise the balance of motivations to meet the needs of different players and therefore producing successful global game designs.'

It is worthy of note that approximately 75-80% of the sales revenue generated by the \$10 billion game industry are derived from male game industries. (Nzegwu, 2000). Boys between the ages of 8 and 14 years are the core audience, being five times more likely than girls to own a Genesis or SuperNintendo computer game system (Subrahmanyam, Greenfield, Krauf and Gross, 2001).

Purple Moon was a new company devoted to creating games for girls as it had been recognised that the interests of pre-teen and teenage girls were largely ignored with regards to established gaming companies. They found that girls prefer games that contain social dynamics and relationships that are part of their everyday activities preferring narrative play and narrative complexity more than do boys. Their games avoided conflicts between good and evil and have storylines and characters that can be developed. Interaction games are rarely competitive in nature and use real-life locales with strong female characters that are in charge of decisions and actions. Characters within the games should demonstrate personal relevance to the girls lives and behave in ways similar to people they know. Boys prefer to get lost in a fantasy world with characters that have no or fewer similarities and connections to their lives (Laurel, 2003).

Girls prefer adventure games whereas boys prefer action games with fantasy based action heroes with super powers. For boys, the goal is to win where the outcome is black and white i.e. die and start again where there is only one solution, for girls the goal is to explore and have new experiences that have degrees of success and varying outcomes. For boys, speed and action is a key component of the game whereas girls prefer discovery and strong story lines. Boys favour settings that are non-realistic and larger than life, girls prefer real life settings with new places to explore. Success for boys comes through elimination of competitors whereas for girls, success comes through the development of friendships. (Agosto, 2002, Dejean, Uptis, Koch and Young, 1999; Inkpen, Booth, Klawe and Uptis. 1994; Kafai, 1996).

Despite studying play and gender differences found among children between ages seven and twelve years the company floundered as it took the all too familiar route of fashion design type games. As Mattell already has the Barbie range of computer games, Purple Moon was unable to compete. Despite their knowledge of the social dynamics and relationships that guide the every day activities of girls, also the private more internal conflicts, questions and insecurities that girls struggle with, often alone, Purple Moon failed to find the recipe for success. Continued research is crucial to find games and educational software that will capture the imagination and interest of girls and boys alike.

The findings that females prefer games that involve social interaction and cooperation is not surprising. Eisenberg (1998) stated that females derive satisfaction from personal interaction in a social group re speech, psychology,

intuition and diplomacy. Eisenberg suggested that these factors are the primary chemically rewarded behaviours that females are hard-wired to pursue. Women are generally judged on the quantity and quality of their relationships and are related to their status within a peer group. Inkpen, Upitis and Anderson (2001) agree that girls are more likely to play a computer game if there is a possibility of interacting with others while they play.

There is a new generation of “Toys To Think With” which combines technology with entertainment allowing children to learn complex concepts. These toys are also at the early stages of development at the MIT Media Lab and includes computational jewelry, stackable, computerised blocks that can “talk” to each other, and the “Bitball” which is similar to a traditional ball but contains a small computer which runs a computer allowing children to write on a desktop computer.

A further new development is Webquest that allows students to play and build interactive simulation games using the World Wide Web as a research medium. WebQuest enables adolescents to formulate and construct artifacts that are personally meaningful, these they call “quests”. The understanding is that if the quest is meaningful to the individual then they have ownership and control of their world. Using the W.W.W. they can then gain knowledge that can be integrated into the theme of their own questworld, whilst gaining knowledge about the construction of a game. This appears to be a successful way of combining what is known about the differences in game play between males and

females. The players construct a world that is appropriate for them whether it be fantasy based or more true to life.

It is therefore crucial for games and educational companies to not only recognise that there are differences, whether they be sex differences or gender differences but to constructively do something about it i.e. the development of more suitable interfaces and the creation of gender specific and gender neutral games. Further research is needed into why it is that as girls mature, their interest in computer games and the time they are prepared to invest in game play declines.

Girls lack of interest will be reflected in a life where technology will play a less significant role than it does for their male counterparts. The negative representation of female characters in most games can lead users to internalise stereotypes of women as being weak and easily victimised. This is a stereotype that women have spent the past 100 years and more specifically the past 40 years trying to eradicate. In this present research it was evidenced that self-perception did indeed have an impact on performance but not necessarily in the anticipated direction.

Computer games that involve negative representations will discourage females from wishing to play such games therefore positive role models have to be encouraged. It would be farcical to consider Lara Croft as a positive role model as her pneumatic embellishments make it all too obvious why she has been included in an otherwise male orientated adventure game. Her character encourages negative self-perception and discourages practice amongst potential

female game players and may encourage negative stereotypical perceptions for young and impressionable males.

Design issues must be considered for encouraging girls into computer technology from an early age. Research by Funk, Jenks and Bechtoldt (2001) have recognised that girls want to be part of the characters lives that they are playing and that there should be a rich, narrative environment. Girls generally prefer challenging games more so than boys who prefer winning and competition. Girls generally like to use skills such as diplomacy, negotiation, compromise and manipulation and they want to find solutions to socially significant problems. Girls generally want a non-confrontational resolution; boys want whatever it takes to win.

Games should encourage positive self-perception and motivational attributes. Less gender specific games would offer opportunities to solve problems and puzzles whereby the players can manipulate or even design parts of the game therefore making the game their own. Gender-neutral games would include adventure games that are enjoyed by both males and females (Harris, 1999) and have a gender- neutral story.

It has been stated that practice with video games can lead to the improvement of spatial skills and therefore early computer experience may serve as a motivation to study computer programming or computer related activities. By encouraging young females to take part in computer games or learning at school through interaction with VEs, then more females may be encouraged to study computer

sciences and enter computer related careers. It is therefore clear that further research is needed to find ways around the environmental factors that hold females back and to find ways to aid those differences in performance that occur through sex differences.

8.10. Conclusion.

This research set out to investigate whether the gender differences found in performance within Virtual Reality (VR) are due purely to innate spatial ability differences or due to, at least in part, environmental factors. The project objectives were achieved in that it was shown that biological factors alone cannot explain why males generally perform better than females within VR. Psychology has for some time accepted that Nature and Nurture cannot be separated therefore it is not enough to say that males have a biological advantage with regards to spatial ability and that is why they are better at navigation, visualisation, mental rotation etc. all of which are important to successful performance within a virtual environment.

The results from this study has shown that in the majority of cases the males were not better than females at MRTs which have traditionally been used to measure spatial ability and have consistently shown robust differences. This in itself is an important contribution to knowledge. Environmental factors such as motivation, self-perception and practice have, in this study, shown their impact on performance. Fortunately each of these factors can be researched and used to improve performance in many areas of life not just with regards to learning scenarios. Mental rotation ability *per se* is not at the root of poor performance within a virtual environment although it is a factor that has to be considered. Sex

differences on their own cannot account for why it is that females perform less well than their male colleagues in virtual environments, however there are navigational differences that successful interface design can overcome. When testing performance within a VE, the methodology must be valid and reliable.

Another important contribution to knowledge and worthy of empirical investigation was the correlation between math ability and spatial ability. The assumption that they are positively correlated has only been borne out for males. In the third phase of testing, females with high math grades performed as well as females with low or no math grades on the mental rotation tests indicating that spatial ability did not necessarily underpin math ability and that as far as females are concerned, math ability, spatial ability and sex are independent whereas for boys, they are co-dependent.

Gouchie and Kimura (1991) found that on mathematical reasoning tests, for males, there was a correlation between testosterone levels and performance, with low-androgen men testing higher. With regards to females, they found no relationship with math scores. This then might explain Benbow's (1988) proposal that high mathematical ability has a significant biological determinant as she reported consistent sex differences in mathematical reasoning ability favouring males. These differences were most pronounced at the upper end of the distribution, where males outnumber females 13 to one.

The findings from this present research may be because the participants with the higher math grades were not necessarily from the upper end of math ability. The

females may have been using strategies other than mental rotation to solve the MRTs and their strategies were as effective as the males with the higher math grades who do use their spatial abilities to solve both mathematical and mental rotation problems. It is only at the upper end of the distribution that the female strategies fail whereas the male strategy, which is linked to biological determinants, prevails.

Sex or gender differences are only two issues that have to be considered when researching performance and individual differences concerning VR. This present study only looked at spatial ability and specifically mental rotation whereas there are a great many areas that should also be studied. People in general have different opportunities and abilities. The very young and the very old have their own impediments to using any form of computer technology. The use of VR for instance could be of great benefit to the handicapped via computer aided communication, rehabilitation, entertainment and education. Research into such areas are still in their infancy considering computer applications are becoming more and more prevalent in every day life. It is therefore important that there are no barriers to computer technology and that everyone has equal access and opportunities for such interaction.

Appendices

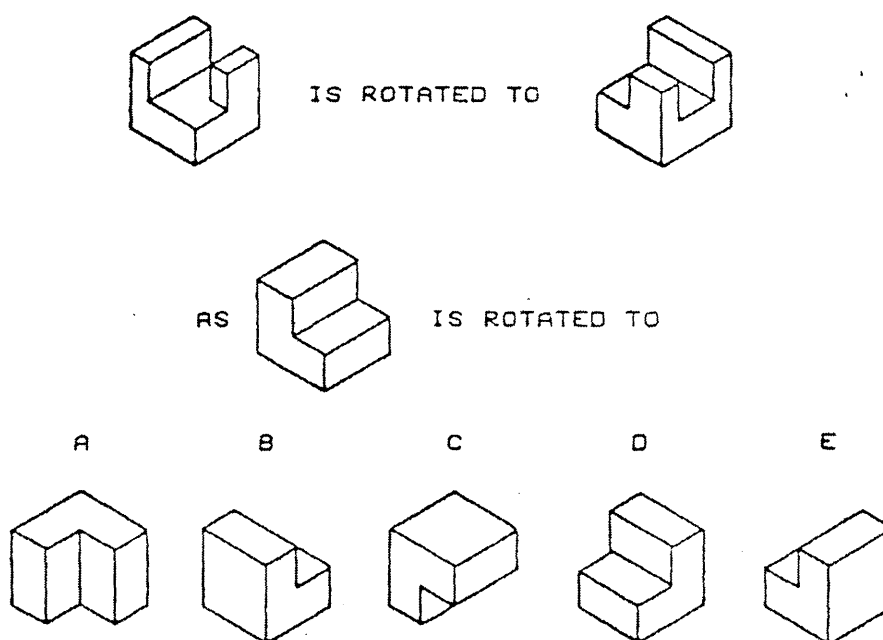
Appendix 1

Copy of the ROT test paper instructions.

Do NOT make any marks on this exam.
Mark your answers on the separate answer sheet

DIRECTIONS

This test consists of 20 questions designed to see how well you can visualize the rotation of three-dimensional objects. An example of the type of question included in this test is shown below.



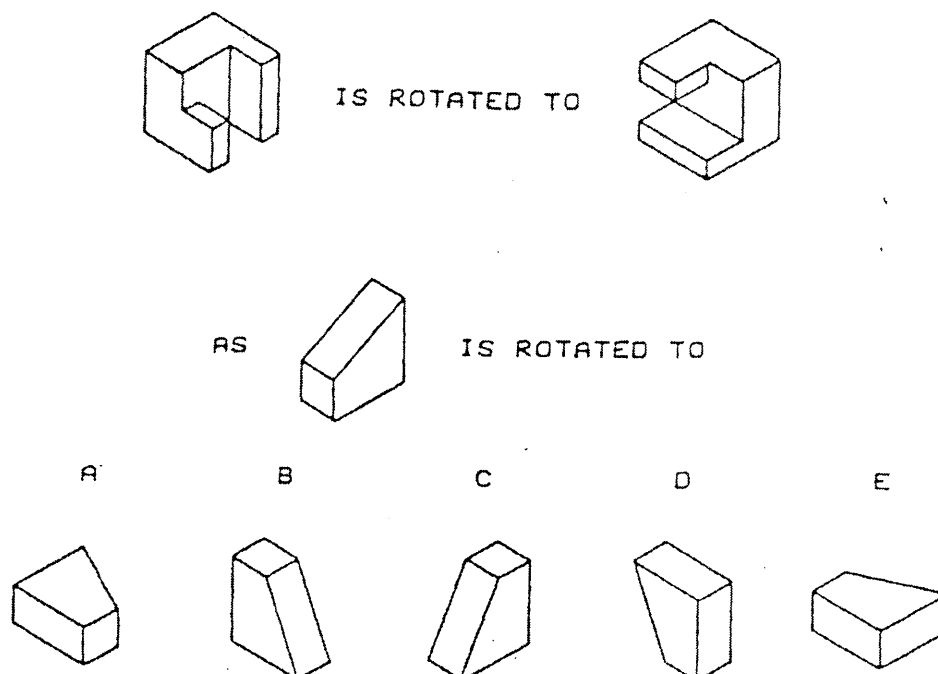
For each question, you should:

- I. Study how the object in the top line of the question is rotated.
- II. Picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner.
- III. Select from among the five drawings (A, B, C, D, or E) given in the bottom line of the question the one that looks like the object rotated in the correct position.

What is the correct answer to the example shown above?

Answers A, B, C, and E are wrong. Only drawing D looks like the object after it has been rotated. Remember that each question has only one correct answer.

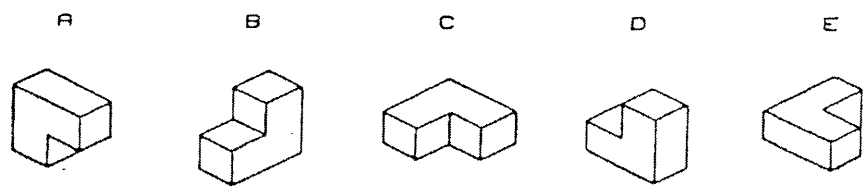
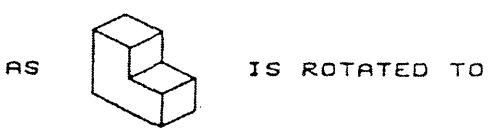
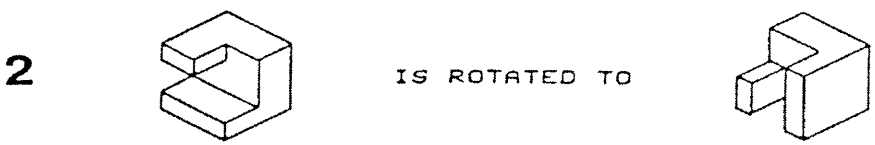
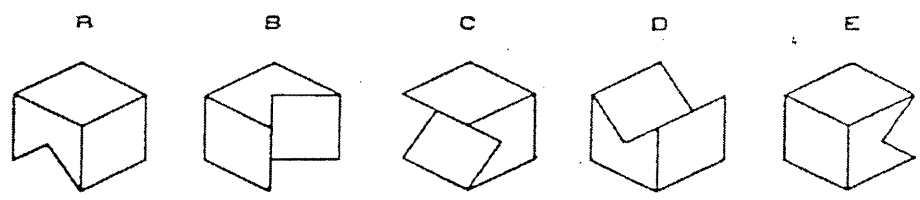
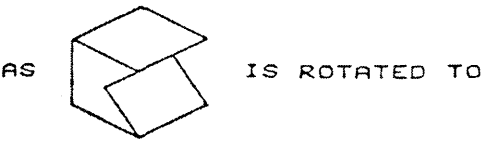
Now look at the example shown below and try to select the drawing that looks like the object in the correct position when the given rotation is applied



Note that the rotation in this example is more complex. The correct answer for this example is B.

Do NOT make any marks in this booklet.
Mark your answers on the separate answer sheet.
You will be told when to begin

Appendix 2. Two examples from the ROT



Appendix 3

QUESTIONNAIRE

Please complete the questionnaire as accurately as possible by ticking the appropriate box

- **Gender.....**MALE ☐ FEMALE ☐
- **Age.....**18-29 ☐ 30-39 ☐ 40> ☐
- **How many A LEVEL/HIGHER Maths subjects did you take at High**
0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐
- **What was the mean grade across the subjects?**
E ☐ D ☐ C ☐ B ☐ A ☐
(Or equivalent)
- **Roughly how many hours a week do you play video/computer games?**
NONE ☐ TWO ☐ FOUR ☐ SIX ☐ EIGHT ☐ MORE ☐
- **How many years computer experience have you had?**
NONE ☐ >1 ☐ >2 ☐ >4 ☐ >6 ☐ 6> ☐

Appendix 4

Subject information sheet

As a volunteer you will be asked to carry out four cognitive tasks regarding spatial ability.

1. A paper and pencil test entitled the Purdue Visualisation of Rotations Test.
2. A 3D mental rotation task using wire-framed shapes presented on a computer screen and viewed via shutterglasses giving the impression of three dimensions.
3. A 3D mental rotation task using solid shapes presented on a computer screen and viewed via shutterglasses giving the impression of three dimensions.
4. A navigation task presented on a computer screen and viewed via shutterglasses giving the impression of three dimensions. You will be given twenty minutes to navigate throughout a virtual house. After twenty minutes of familiarising yourself with the environment, you will be asked to perform five short way-finding tasks and to write answers to a number of navigating questions.

Prior to the testing taking place you will be asked to sign a consent form. The consent form confirms that you have been advised of the possible side effects of navigating within a virtual environment. The navigation task may cause you to experience a mild form of “motion sickness” and on rare occasions to experience severe nausea. If you suffer from **labyrinthitis, vertigo, menieres disease, hypertension or heart disease** you will not be accepted as a subject incase the condition is exacerbated. Should you be in the first trimester of pregnancy you are advised not to take part in the experiment.

Should you feel ill during the testing procedure you may discontinue the experiment at any time and are under no obligation to continue or to repeat the test at another time.

When the test is aborted or completed, whether you feel nauseous or not, you will be offered refreshments and invited to sit in a well-lit area. You will leave the premises only when you feel ready to do so. Should you feel dizzy at any time after the experiment you are advised not to drive or to operate any heavy plant machinery. Within 24 hours of conducting the experiment you will be contacted to ascertain your general feeling of well-being.

Appendix 5

Consent Form

I hereby acknowledge that I have read the accompanying information sheet and confirm that, to the best of my knowledge, I do not have any of the following conditions:

- Labyrinthitis
- Vertigo
- Menieres Disease
- Hypertension
- Heart Disease

I am also aware that “cybersickness” may exacerbate the feeling of nausea experienced by women in the first trimester of pregnancy.

As per the instruction sheet, I am aware that I can terminate the testing procedure at any time and am under no obligation to continue at another time. I have also been advised not to drive or operate heavy plant machinery should I feel any symptoms of giddiness during the 24 after the test.

I hereby give consent to be a subject in the spatial ability experiment

SIGNATURE

.....

NAME (IN CAPITALS)

.....

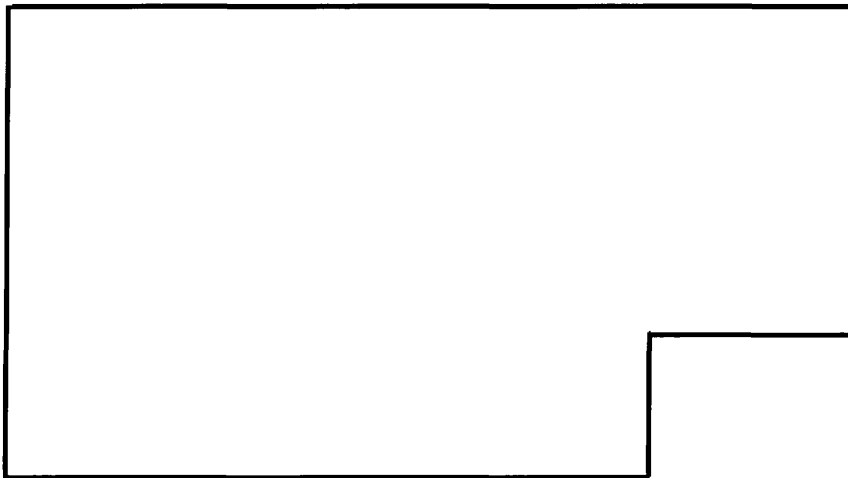
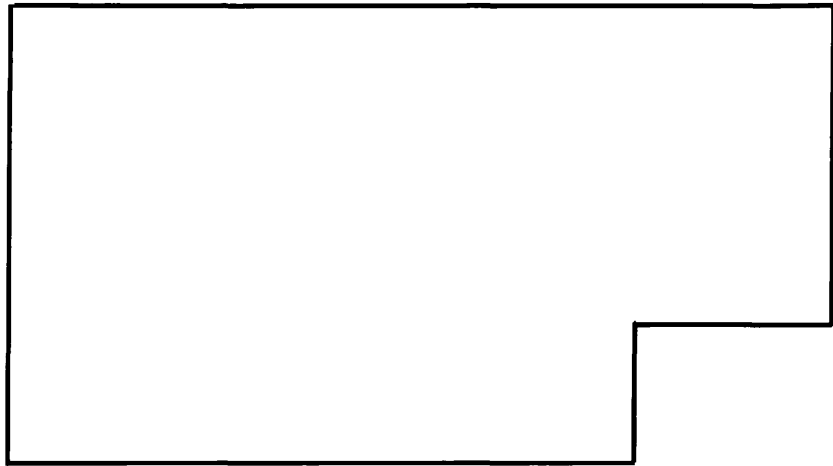
Appendix 6

Way-finding instructions (presented randomly)

1. Starting from the sofa in the lounge, take the most direct route to the walk-in-wardrobe in the master bedroom. There is a patterned shirt, tag it and then head for the playroom. In the playroom, tag two photographs attached to the pin-board. Return to the sofa in the lounge.
2. Starting from the sofa in the lounge, take the most direct route to the bathroom in the granny flat. Tag the dirty towels in the W.C. and proceed to tag the washing machine in the utility room. There are a further two bathrooms upstairs, tag the towels from each of the bathrooms and return to the washing machine in the utility room which you tag again. Returning to the sofa in the lounge.
3. Starting from the sofa in the lounge, exit the house via the patio doors in the den. Make your way to the window that looks into the granny flat. What is laying on the coffee table? Returning by the same route, head straight to the office and tag the pad on the table. Return to the sofa in the lounge.
4. Starting from the sofa in the lounge, go to the kitchen and tag a bottle of wine in the wine store. Go outside via the back door to the pool area. There are no sun-chairs so go to the cellar to find some. How many sun-chairs do you find? Return to the sofa in the lounge.
5. It is cleaning time! Starting from the sofa in the lounge, there are six toilets in the house. Going by the most direct route tag each toilet before returning to the lounge.

Appendix 7

House Layout



Draw the layout of the house to the best of your ability.

Appendix 8

Visualisation/Alternative routes test

1. From the office there are three routes that can be taken to the pool, one is direct, two are indirect. Can you describe the three routes to someone visiting the house for the first time?

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Appendix 9

Visualisation and Orientation

1.If you are in the playroom, in front of and looking at the pin-board, what is immediately behind you?

2. If you look out of the window in the granny flat, would you walk to your left or right to get to the back door?

3. You are standing at the back door looking out; do you turn left or right to head towards the pool?

4. You are in the kitchen with your back to the wine store, to go to the den would you go through the door on your right or the door on your left?

5. You are standing in the entrance hall, ready to turn right heading for the office. What is on your immediate right?

THANK YOU FOR TAKING PART IN THIS STUDY.

Appendix 10

Landmarks

How many landmarks can you remember? A landmark can be anything from a distinctive carpet to a table.

- 1
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ANOVAs

1. Results of the ROT (accuracy) ANOVA in phase one experiments.

Source	SS	df	MS	F-value	Sig-level
GENDER	1.39	1	1.39	0.10	0.75
FACULTY	32.14	1	32.14	2.3	0.13
AGE	8.45	1	8.45	0.6	0.44
GENDER *FACULTY	0.13	1	0.13	0.01	0.92
GENDER *AGE	3.29	1	3.29	0.24	0.63
FACULTY *AGE	0.86	1	0.86	0.06	0.81
GENDER *FACULTY *AGE	25.04	1	25.04	1.79	0.18

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

2. Results of the Wire-frame (time) ANOVA in phase one experiments.

Source	SS	df	MS	F-value	Sig-level
FACULTY	83.24	1	83.24	0.004	0.95
GENDER	19513.99	1	19513.99	0.83	0.37
AGE	68009.55	1	68009.55	2.89	0.09
FACULTY *GENDER	111484.97	1	111484.97	4.74	0.03
FACULTY *AGE	162.46	1	162.46	0.01	0.52
GENDER *AGE	4036.81	1	4036.81	0.17	0.68
FACULTY *GENDER *AGE	995.54	1	995.54	0.04	0.84

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

3. Results of the Wire-frame (correct) ANOVA in phase one experiments.

Source	SS	df	MS	F-value	Sig-level
FACULTY	419.98	1	419.98	8.9	0.004
GENDER	8.07	1	8.07	0.17	0.68
AGE	36.53	1	36.53	0.77	0.38
FACULTY *GENDER	15.72	1	15.72	0.33	0.57
FACULTY *AGE	95.65	1	95.65	2.03	0.16
GENDER *AGE	50.79	1	50.79	1.08	0.30
FACULTY *GENDER *AGE	29.05	1	29.05	0.62	0.44

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

4. Results of the Solid (correct) ANOVA in phase one experiments.

Source	SS	df	MS	F-value	Sig-level
FACULTY	142.62	1	142.62	3.45	0.07
GENDER	189.42	1	189.42	4.58	0.04
AGE	231.67	1	231.67	5.60	0.02
FACULTY *GENDER	3.53	1	3.53	0.09	0.77
FACULTY *AGE	11.86	1	11.86	0.29	0.59
GENDER *AGE	18.37	1	18.37	0.44	0.51
FACULTY *GENDER *AGE	12.61	1	12.61	0.31	0.58

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

5. Results of the Solid (time) ANOVA in phase one experiments.

Source	SS	df	MS	F-value	Sig-level
FACULTY	124910.38	1	124910.38	7.13	0.10
GENDER	12735.13	1	12735.13	0.73	0.40
AGE	8394.64	1	8394.64	0.48	0.49
FACULTY *GENDER	73843.26	1	73843.26	4.21	0.44
FACULTY *AGE	53641.27	1	53641.27	3.06	0.09
GENDER *AGE	162.46	1	162.46	0.009	0.92
FACULTY *GENDER *AGE	40246.11	1	40246.11	2.30	0.14

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

6. Results of the MOTIVATION TEST (accuracy) ANOVA in phase two experiments.

Source	SS	df	MS	F-value	Sig-level
MOTIVE	1786.03	1	1786.03	22.65	0.00
GENDER	8.69	1	8.69	0.11	0.74
MOTIVE *GENDER	195.40	1	195.40	2.48	0.12

A 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE) AND MOTIVATION (WITH, WITHOUT).

7. Results of the SELF-PERCEPTION test ANOVA in phase two experiments.

Source	SS	df	MS	F-value	Sig-level
SELFPERC	4354.04	2	2177.02	6.85	0.002
GENDER	8760.87	1	8760.87	27.55	0.000
AGE	758.55	1	758.55	2.39	0.13
SELFPERC *GENDER	2459.84	2	1229.92	3.87	0.02
SELFPERC *AGE	50.66	2	25.33	0.08	0.92
GENDER *AGE	567.49	1	567.49	1.79	0.18
SELFPERC *GENDER *AGE	359.70	2	179.85	0.57	0.57

A 3 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY SELFPERCEPTION (GIRLSBEST, BOYSBEST, CONTROL), GENDER (MALE, FEMALE) AND AGE.

8. Results of the ROT (accuracy) ANOVA in phase three experiments.

Source	SS	df	MS	F-value	Sig-level
FACULTY	4021.82	1	4021.82	9.74	0.003
GENDER	0.974	1	0.974	0.002	0.96
AGE	30.59	1	30.59	0.07	0.79
FACULTY *GENDER	656.51	1	656.51	1.59	0.21
FACULTY *AGE	548.99	1	548.99	1.33	0.26
GENDER *AGE	721.51	1	721.51	1.75	0.19
FACULTY *GENDER *AGE	510.65	1	510.65	0.27	0.03

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

9.Results of the LAYOUT test ANOVA in phase three experiments.

Source	SS	df	MS	F-value	Sig-level
FACULTY	298.45	1	298.45	9.24	0.004
GENDER	53.09	1	53.09	1.64	0.21
AGE	37.94	1	37.94	1.18	0.28
FACULTY *GENDER	64.16	1	64.16	1.99	0.17
FACULTY *AGE	18.82	1	18.82	0.58	0.45
GENDER *AGE	41.27	1	41.27	1.28	0.26
FACULTY *GENDER *AGE	173.17	1	173.17	5.36	0.03

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

10.Results of the LANDMARK test ANOVA in phase three experiments.

Source	SS	df	MS	F-value	Sig-level
FACULTY	8.01	1	8.01	0.72	0.40
GENDER	21.99	1	21.99	1.97	0.17
AGE	22.64	1	22.64	2.03	0.16
FACULTY *GENDER	3.05	1	3.05	0.27	0.60
FACULTY *AGE	2.61	1	2.61	0.23	0.63
GENDER *AGE	23.11	1	23.11	2.07	0.16
FACULTY *GENDER *AGE	4.89	1	4.89	0.44	0.51

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

11. Results of the VISUALISATION test ANOVA in phase three experiments.

Source	SS	df	MS	F-value	Sig-level
FACULTY	0.87	1	0.87	0.90	0.35
GENDER	9.123E-02	1	9.123E-02	0.09	0.76
AGE	22.64	1	22.64	2.03	0.16
FACULTY *GENDER	1.64	1	1.64	1.71	0.19
FACULTY *AGE	0.25	1	0.25	0.26	0.61
GENDER *AGE	4.04	1	4.04	4.2	0.46
FACULTY *GENDER *AGE	1.81	1	1.81	1.88	0.18

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

12. Results of the ORIENTATION test ANOVA in phase three experiments.

Source	SS	df	MS	F-value	Sig-level
FACULTY	5.29	1	5.29	6.97	0.01
GENDER	6.389E-02	1	6.389E-02	0.08	0.77
AGE	2.42	1	2.42	3.19	0.08
FACULTY *GENDER	2.66	1	2.66	3.51	0.07
FACULTY *AGE	5.05	1	5.05	6.67	0.01
GENDER *AGE	5.45	1	5.45	7.19	0.10
FACULTY *GENDER *AGE	3.31	1	3.31	4.36	0.04

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

13. Results of the timed NAVIGATION Test ANOVA in phase three experiments.

Source	SS	df	MS	F-value	Sig-level
FACULTY	17.59	1	17.59	4.52	0.01
GENDER	6.71	1	6.71	1.72	0.04
AGE	16.03	1	16.03	4.12	0.05
FACULTY *GENDER	0.36	1	0.36	0.09	0.76
FACULTY *AGE	21.92	1	21.92	5.63	0.02
GENDER *AGE	11.43	1	11.43	2.94	0.09
FACULTY *GENDER *AGE	14.47	1	14.47	3.72	0.06

A 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

14. Results of the Wire-frame and Solid Test (accuracy) ANOVA in phase three experiments.

Within Subjects effects

Source	SS	df	MS	F-value	Sig-level
TASK	125.63	1	125.65	3.16	0.08
TASK* GENDER	129.21	1	129.21	3.25	0.08
TASK* FACULTY	0.28	1	0.28	0.01	0.93
TASK* AGE	9.16	1	9.16	0.23	0.63
TASK* GENDER *FACULTY	41.26	1	41.26	1.04	0.31
TASK* FACULTY *AGE	109.50	1	109.50	3.97	0.05
TASK *GENDER *FACULTY *AGE	60.92	1	60.92	1.53	0.22

Between subject effects

GENDER	14.23	1	14.23	0.11	0.75
FACULTY	2072.32	1	2072.32	15.24	0.00
AGE	53.74	1	53.74	0.40	0.53
GENDER* FACULTY	815.08	1	815.08	5.99	0.02
GENDER *AGE	642.31	1	642.31	4.72	0.04
FACULTY *AGE	54.09	1	54.09	0.40	0.53
GENDER *FACULTY *AGE	424.9	1	424.9	3.13	0.08

A 2 X 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY TASK (WIRE-FRAME, SOLID), GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.

15. Results of the Wire-frame and Solid Test (time) ANOVA in phase three experiments.

Within Subjects effects

Source	SS	df	MS	F-value	Sig-level
TASK	30294.27	1	30294.27	6.03	0.02
TASK* GENDER	3064.83	1	3064.83	0.61	0.44
TASK* FACULTY	7117.47	1	7117.47	1.42	0.24
TASK* AGE	163.03	1	163.03	0.03	0.86
TASK* GENDER *FACULTY	3698.16	1	3698.16	0.74	0.40
TASK* FACULTY *AGE	6083.27	1	6083.27	1.21	0.28
TASK* GENDER *AGE	4674.04	1	4674.04	0.93	0.34
TASK *GENDER *FACULTY *AGE	11714.7	1	11714.7	2.33	0.13

A 2 X 2 X 2 X 2 MIXED ANALYSIS OF VARIANCE BY TASK (WIRE-FRAME, SOLID), GENDER (MALE, FEMALE), FACULTY (ARTS AND SOCIAL SCIENCES, SCIENCE AND ENGINEERING) AND AGE.